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USAAVLABS TECHNICAL REPORT 68-39

A STUDY OF HANDLING QUALITIES REQUIREMENTS OF WINGED HELICOPTERS

By

W. Sardanowsky

H. P. Harper

July 1968

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-382(T)

UNITED AIRCRAFT CORPORATION

SIKORSKY AIRCRAFT DIVISION

STRATFORD, CONNECTICUT

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This report was prepared by the Sikorsky Aircraft Division of the United Aircraft Corporation under the terms of Contract DA 44-177-AMC-382(T). It consists of a study of winged helicopter flying and handling qualities requirements based on mission task performance tolerance requirements and capabilities of these helicopters.

The study presents an approach to defining flying and handling qualities specifications applicable to rotary-wing aircraft having a fixed wing for lift in high-speed flight.

This report is published for the dissemination of information and the stimulation of new ideas.

Task 1F125901A14233
Contract DA 44-177-AMC-382(T)
USAAVLABS Technical Report 68-39
July 1968

A STUDY OF HANDLING QUALITIES REQUIREMENTS OF WINGED HELICOPTERS

SER - 50489

by

W. Sardanowsky
H. P. Harper

Prepared by

United Aircraft Corporation
Sikorsky Aircraft Division
Stratford, Connecticut

for

U.S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

SUMMARY

The purpose of this study was to establish a basis for the mission task performance oriented approach to a flying and handling qualities requirements specification. In this approach, the design specifications are derived from flying and handling qualities required to efficiently perform a design mission.

The study was divided into the following steps:

1. Determine typical VTOL Army missions and flight tasks critical to accomplishing these missions.

2. List specifications pertinent to winged helicopter flying and handling qualities, from currently used and proposed V/STOL and CTOL specifications.

3. Determine the influence of these specifications on the aircraft's ability to perform critical mission tasks by comparing critical task performance flight test data with the aircraft's conformance to specifications listed in item 2.

4. Determine new specifications not covered in item 2 but found to be necessary to meet critical mission task performance requirements in item 3.

5. Combine the findings of this study into a set of mission task performance oriented flying and handling qualities specifications for winged helicopters.

Interviews with Army personnel were used to determine typical Army missions, the related critical mission tasks, and task performance tolerances. To complete step 2, a list of items, applicable to winged helicopters, from MIL-H-8501A, MIL-F-8785, AGARD TR-408, and USAAVLABS TR 65-45 was compiled, and tabulated according to the specifications format proposed in this study. Flight test data from Bell Helicopter Company, Kaman Aircraft Corporation, Lockheed Aircraft Company and Sikorsky Aircraft were to be used for step 3.

Unavailability of data precluded the determination of the relationship between flying and handling qualities and design parameters. However, the results of this study form a base for work toward mission task performance oriented flying and handling qualities specifications. The requirement for such specifications has been amply demonstrated by comments from military personnel contacted during this study.

FOREWORD

This study was performed by the Sikorsky Aircraft Division of the United Aircraft Corporation, under the sponsorship of the United States Army Aviation Materiel Laboratories (USAAVLABS), Contract DA-44-177-AMC-382(T), and was monitored by Mr. Richard L. Scharpf of the Applied Aeronautics Division.

This report describes a study of winged helicopter handling qualities requirements based on the philosophy of the mission task performance oriented approach.

Appreciation is extended to personnel of the Lockheed-California Company, the Kaman Aircraft Corporation, Bell Helicopter Company, and specifically to personnel from USAAVLABS, Fort Eustis, Virginia, the Army Infantry School, Fort Benning, Georgia and the Army Aviation School, Fort Rucker, Alabama.

All constructive comments, suggestions and recommendations are solicited and should be forwarded to:

Commanding Officer
U.S. Army Aviation Materiel Laboratories
ATTN: SAVFE-AA
Fort Eustis, Virginia 23604

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LIST OF SYMBOLS

ANIP	Army Navy Instrumentation Program
ASE	automatic stabilization equipment
$C_{1/2}$	number of cycles for the lateral oscillations to damp to half amplitude
CG	center of gravity
cps	cycles per second
CTOL	conventional takeoff and landing
deg	degrees
f_d	damped frequency, cycles per second
fpm	feet per minute
ft	feet
g	acceleration of gravity
G.W.	gross weight
HEL	Human Engineering Laboratory
IFR	instrument flight rules
IGE	in ground effect
ILS	instrument landing system
I_x	moment of inertia about the x axis, slug-ft^2
I_y	moment of inertia about the y axis, slug-ft^2
I_z	moment of inertia about the z axis, slug-ft^2
kn	knots
$\mathrm{Log}_e\ T$	natural logarithm of period in seconds

Δn	load factor increment
n_L	limit load factor based on structural considerations
NLF	normal load factor
OGE	out of ground effect
rad	radians
ROC	rate of climb
rpm	revolutions per minute
SAS	stability augmentation system
sec	seconds
T	period, seconds
V_{con}	conversion speed, i.e. speed at which aircraft achieves a conventional configuration
V_{max}	maximum velocity
VFR	visual flight rules
V/STOL	vertical and short takeoff and landing
β	sideslip angle, degrees
ζ	damping ratio, ratio of actual damping to critical damping
$\frac{\vert\phi\vert}{\vert V_e\vert}$	ratio of magnitude of bank angle to equivalent side velocity, degrees per feet per second

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INTRODUCTION

The constant growth in complexity of Army missions has caused a parallel rise in performance and flying and handling qualities requirements for aircraft used in fulfilling these missions. An aircraft which shows great promise for meeting these requirements is a compound helicopter. Since no design specifications exist for winged helicopters, the advent of such helicopters has caused a critical review of the presently used and proposed specifications which may be used in their design. The reviewed specifications included both CTOL and V/STOL specifications, such as MIL-H-8501A, MIL-F-8785, AGARD TR 408, and USAAVLABS TR 65-45. They specify parameters which may make the aircraft flyable, but they have no established relationship to the aircraft's ability to perform its design mission. Thus, it is feasible to have an aircraft which meets all the applicable current specifications, but whose flying and handling qualities preclude the performance of some critical tasks in the design mission, rendering the aircraft ineffective. This problem has been the subject of numerous studies conducted by Sikorsky Aircraft over the past years. As a result of these studies, the philosophy of a mission task performance oriented approach to the establishment of flying and handling qualities requirements evolved. The fundamental premise of this philosophy is that design specifications must be based on task performance requirements and tolerances and flying and handling qualities requirements of the design mission.

The purpose of this study was to determine if sufficient data were available to write mission task performance oriented design specifications for winged helicopters, and to write these specifications if the data were available.

The first step in the study was the determination of typical winged helicopter missions. Three mission categories were established, with the winged helicopters divided into three classes according to the intended design mission. The missions were broken down into mission segments, and these in turn were subdivided into mission tasks. Performance tolerances for these mission tasks were established for the three classes of winged helicopters through interviews with military personnel with actual experience in performing the missions, and by Sikorsky in-house studies.

In order to evaluate the relationship between current specifications and mission task performance capability, applicable portions of MIL-H-8501A, MIL-F-8785, AGARD TR-408, and USAAVLABS TR 65-45 were summarized. These summaries in turn were combined into one set of specifications by retaining only the most demanding items under each specification, thus facilitating correlation with flight test data. In cases of conflicting or incompatible requirements, all applicable specifications were retained. A comparison of the degree to which the aircraft conforms to a given specification and its mission task performance capability was to be used in evaluating the specification's applicability under the mission task performance oriented approach.

The correlation of design parameters and mission task performance capability was to be established from available winged helicopter flight test data and interviews with personnel involved in winged helicopter design and testing. Data acquired by Bell Helicopter Company, Kaman Aircraft Corporation, Lockheed Aircraft Company, and Sikorsky Aircraft were to be considered. Discussions were held with personnel involved in the design and testing of winged helicopters at these companies. Winged helicopter flight test reports published by the above companies were also collected, and a list of all applicable data was compiled.

Examination of available data showed that winged helicopter flight tests conducted by the companies considered in this study were aimed at attainment of high speeds. No qualitative evaluations of the aircraft's handling qualities or task performance capability were performed. Thus, only parts of the Specification Conformance Evaluation Form and Winged Helicopter Test-Bed Flying and Handling Qualities Evaluation Questionnaire could be completed for the aircraft under consideration. Since only limited pilot opinion data regarding the aircraft's mission task performance capability could be obtained, none of the Mission Task Performance Capability Evaluation Questionnaires could be completed. Instead, a list of handling qualities problem areas traceable to the winged helicopter configuration was compiled from these data.

Although the available data precluded the establishment of mission task performance oriented winged helicopter flying and handling qualities criteria, the secondary goals of this study were attained. Winged helicopter classifications, mission tasks, and mission task performance tolerances were determined. Applicable current specifications and mission tasks to be performed were listed. This permitted the formulation of a plan for additional studies which will provide the data necessary for a comprehensive evaluation of relationships between current flying and handling qualities specifications, mission task performance capability, and aircraft design parameters.

The results of this study are summarized in four sections: (1) Army Mission Task Performance Requirements, (2) Proposed Specifications Format and Items from Current Specifications Applicable to Winged Helicopters, (3) Design Factors to be Considered in Formulation of Winged Helicopter Design Specifications, and (4) Plan for Additional Studies.

ARMY MISSION TASK PERFORMANCE REQUIREMENTS

The suitability of an aircraft for a given mission is determined by evaluating how well it can perform the critical mission tasks; i.e., tasks whose performance within some mission imposed tolerances is a requirement to mission accomplishment. The mission task performance oriented approach to flying and handling qualities specification used in this study is based on the same principles. Army missions are determined, and the related critical mission tasks and task performance tolerances are established. These in turn are used in determining the flying and handling qualities requirements for a given mission and class of aircraft.

As a first step in this study, major Army missions were determined from consultations with USAAVLABS personnel and from Sikorsky in-house studies. The missions were divided into three major classifications, each classification with similar task performance requirements and tolerances. Since aircraft are classified according to their design mission, three major aircraft classifications were established:

- I Utility and Support Transport
- II Tactical Transport and Rescue
- III Fire Support and Surveillance

Each class of aircraft is believed to have similar flying and handling qualities, based on its mission task performance requirements.

Mission profiles for the three mission classes (Figure 1) and associated task performance tolerances were established in meetings held at USAAVLABS, Fort Eustis, Virginia; at the Army Aviation School, Fort Rucker, Alabama; and at the Army Infantry School, Fort Benning, Georgia. Army personnel who took part in the meetings included pilots, instructors, field commanders, and other personnel involved in planning and executing Army V/STOL missions. The mission task performance tolerances were based on opinions of the personnel interviewed during the meetings and, thus, are subject to verification by measurements taken during actual performance of the tasks. Such measurements could be obtained only by conducting a flight test program specifically designed for this purpose.

The mission tasks and task performance tolerances for the missions shown in Figure 1 are grouped according to the flight regimes in which they are performed and presented in Tables I through IV. The four flight regimes considered were; hover (0 to 3 kn), low speed flight (3 to 120 kn), transition (60 to 150 kn), and high speed flight (120 kn to V_{max}), respectively.

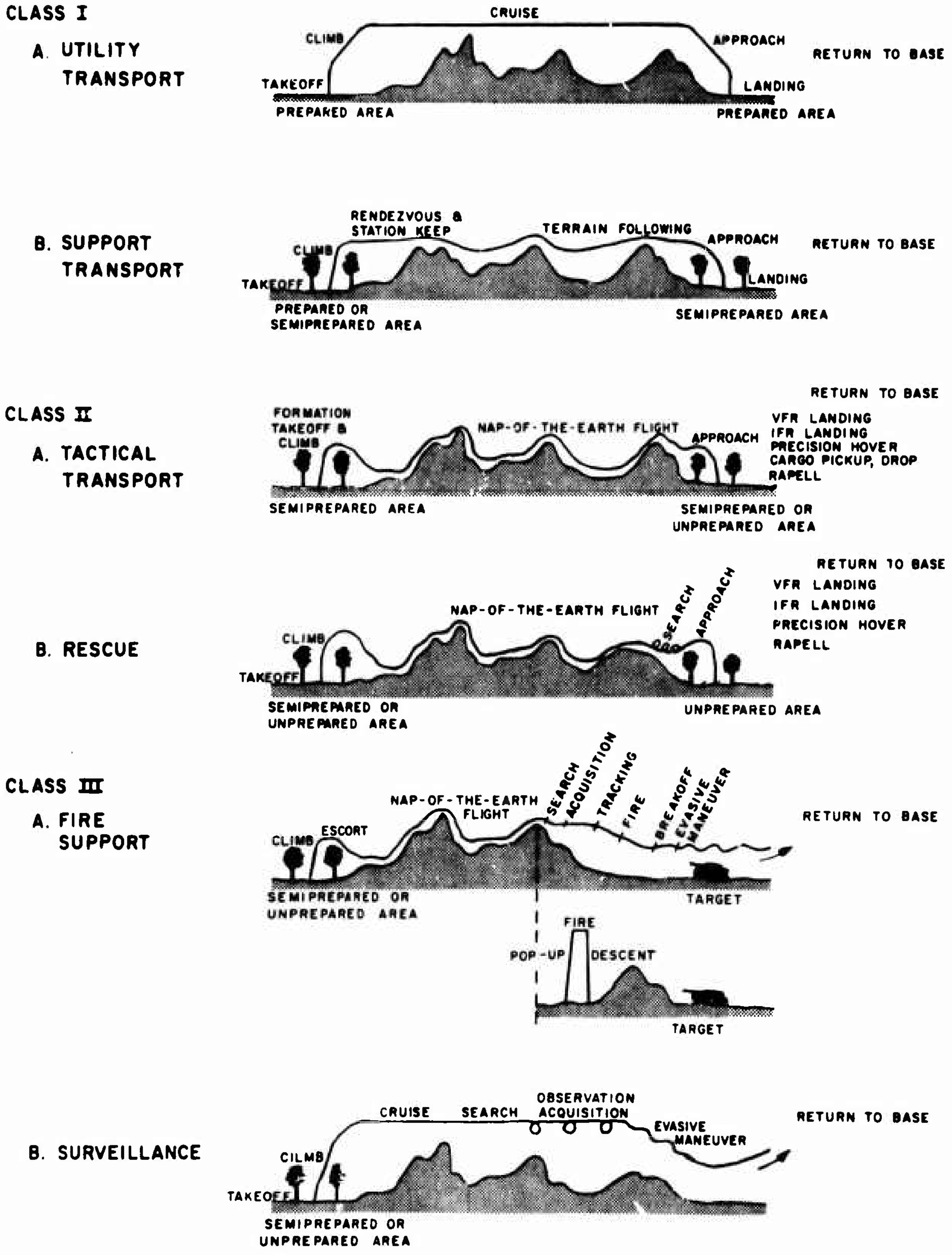

Figure 1. Mission Profiles.

TABLE I HOVER, (0 to 3 kn), TASK PERFORMANCE REQUIREMENTS

Aircraft Class (Task)	Class I	Class II	Class III
Spot Hover (IGE)	Keep the aircraft's C.G. within a 12-ft-radius circle. attitude ±5 deg. upwind heading ±10 deg. altitude ±5 ft.	Same as Class I except maintain downwind heading ±10 deg. in 30-kn winds.	Same as Class II
		With gusts up to 10 kn, VFR maintain (for at least 3 min) aircraft's C.G. within a 3 ft-radius circle. Altitude ±3 ft, zero ground speed ±5 kn, heading and attitude ±3 deg.	No IGE Hover Requirement
Spot Hover (OGE)	No OGE requirement	In gusts up to 10 kn, VFR maintain (for at least 3 min) altitude 200 ft, ±10 ft. C.G. within a 10-ft radius circle. Zero ground speed ±10 kn, heading and altitude ±5 deg.	Same as Class II
360° Hovering Turns (IGE, OGE)	Same as spot hover (start and stop within ±10 deg of prescribed heading).	Same as spot hover (start and stop within ±10 deg of prescribed heading)	Same as spot hover (start and stop within ±10 deg of prescribed heading)
Vertical Climb	Same as spot hover except altitude. (Climb at ____ fpm to prescribed altitude, ±5 ft)	Same as spot hover except altitude. (Climb at ____ fpm to prescribed altitude, ±5 ft)	Same as spot hover except altitude. (Climb at ____ fpm to prescribed altitude, ±5 ft)
Vertical Descent	Same as spot hover except altitude. (Descend from prescribed altitude at ____ fpm, ± ____ fpm, to IGE hover)	Same as spot hover except altitude. (Descend from prescribed altitude at ____ fpm, ± ____ fpm, to IGE hover)	Same as spot hover except altitude. (Descend from prescribed altitude at ____ fpm, ± ____ fpm, to IGE hover)

TABLE II LOW-SPEED FLIGHT, (3 to 120 kn), TASK PERFORMANCE REQUIREMENTS

Aircraft Class (Task)	Class I	Class II	Class III
Cruise	Straight and Level Flight. VFR, in turbulence generated by formation. Maintain altitude ±20 airspeed ±5 kn heading and attitude ±5 deg	Straight and Level Flight. Same as Class I	Straight and Level Flight. Same as Class I
	IFR flight. Maintain altitude ±50 ft airspeed ±5 kn heading and attitude ±5 deg	IFR, in turbulence generated by formation. Maintain altitude ±20 ft airspeed ±5 kn heading and attitude ±5 deg	Same as Class II
	3-deg/sec Turn. Same as straight and level cruise except heading, yaw rate ±1 deg/sec	3-deg/sec Turn. Same as straight and level cruise except heading, yaw rate ± 1/2 deg/sec	3-deg/sec Turn. Same as Class II
Climb	500-fpm Climb. Same as straight, level flight except altitude, ROC ±100 fpm	500-fpm Climb. Same as Class I	500-fpm Climb. Same as Class I
	Climb From Hover. Initial climb, VFR. Acceleration at least 3 kn/sec, heading and roll attitude ±5 deg rate of climb at least 500 fpm	Climb From Hover. Initial climb, VFR. Acceleration at least 5 kn/sec, heading and roll attitude ±5 deg rate of climb at least 1000 fpm	Climb From Hover. Initial climb. VFR. Same as Class II
	Climb, IFR. Climb airspeed ±10 kn heading ±10 deg attitude ±5 deg rate of climb 1000 fpm, ±100 fpm	Climb, IFR. Climb airspeed ±10 kn heading ±5 deg attitude ±5 deg rate of climb 2000 fpm, ±100 fpm	Climb, IFR. Same as Class II
Precision Ground Taxi (IGE)	No requirements	No requirements	No requirements
Lateral Flight	No requirements	No requirements	No requirements

TABLE II - Continued

Aircraft Class (Task)	Class I	Class II	Class III
Acceleration	No specified requirement	No specified requirement	No specified requirement
Descent and Landing	At approach speed, ±10 kn, VFR. Maintain 30 deg descent, ±5 deg, attitude and heading ±3 deg	Same as Class I	Same as Class I
	No IFR requirement	At approach speed, ±5 kn, IFR. Maintain 15 deg. descent, ±3 deg. attitude and heading ±3 deg.	Same as Class II
	Final Approach Starting from descent at 100-ft altitude, touch down within 20 ft of desired spot at less than 5-ft/sec sink rate and 0-10 kn ground speed Maintain upwind heading ±10 deg, roll attitude ±5 deg.	Final Approach Starting from descent at 100-ft ceiling, touch down within 6 ft of desired spot at less than 5-ft/sec sink rate and 0-10 kn ground speed. Maintain downwind heading ±5 deg, roll attitude ±5 deg.	Same as Class II
	Assault Landing No requirement	Assault Landings From cruise speed at 1500-ft altitude, come to landing within 12 ft of desired spot at less than 5-ft/sec sink rate and 0-10 kn ground speed in no more than 75 sec, maintaining downwind heading ±5 deg.	Assault Landing No requirement
		From 80 kn, at 50-to 200-ft altitude, come to landing within 12 ft of desired spot at less than 5-ft/sec sink rate and 0-10 kn ground speed in no more than 16 sec, maintaining downwind heading ±5 deg.	
Deceleration	At least 3 kn/sec	At least 5 kn/sec	At least 8 kn/sec
Pull Out	____ g at ____ kn	____ g at ____ kn	____ g at ____ kn

TABLE II - Continued

Aircraft Class (Task)	Class I	Class II	Class III
Reverse Direction of Flight	At any airspeed above 60 kn establish 15 deg/sec turn rate, ±3 deg/sec, in no more than 5 sec, maintaining airspeed ±10 kn and altitude within -20 to +50 ft	Same as Class I	Same as Class I
Gunnery Run	No requirement	No requirement	In gusts up to 10 kn, VFR, and rates of descent up to 1000 fpm above 60 kn. Maintain pitch attitude and heading ±2 deg, roll attitude ±5 deg, rate of descent ±100 fpm
Tear Drop Maneuver	No requirement	From a speed of 60 kn and a 3000-ft altitude, establish maximum rate of turn and execute landing on point of maneuver initiation in no more than 25 sec (low-speed assault landing touchdown requirement)	From a speed of 60 to 100kn, establish maximum rate of turn, maintaining airspeed ±10 kn, and execute gunnery run on point of maneuver initiation in no more than 8 sec.
Break off Maneuver, VFR	No requirement	Change from 500-fpm rate of descent, ±100 fpm, to 1000 fpm rate of climb, ±100 fpm; and change heading 180 deg, ±10 deg, at any airspeed above 60 kn in no more than 15 sec.	Change from 1000-fpm rate of descent, ±100 fpm, to 2000 fpm rate of climb, ±100 fpm; and change heading 180 deg, ±10 deg, at any airspeed above 60 kn in no more than 15 sec.
Engine Failure	Autorotation Entry, VFR. Starting from speed of 3 to 100 kn, VFR conditions, altitude above 300 ft, touch down within 50 ft of desired spot, maintaining heading ±15 deg, roll attitude ±5 deg, touch down at less than 10-ft/sec sink rate, and zero ground speed ±10 kn.	Autorotation Entry, VFR. Same as Class I	Autorotation Entry, VFR. Same as Class I
	Autorotation Entry, IFR. No requirement	Autorotation Entry, IFR. Starting from speed of 3 to 100 kn, IFR conditions, altitude above 300 ft, touch down within 50 ft of desired spot, maintaining heading ±10 deg, roll attitude ±5 deg, touch down at less than 10-ft/sec sink rate, and zero ground speed ±10 kn.	Autorotation Entry, IFR. Same as Class II

TABLE III TRANSITION FLIGHT, (60 to 150 kn), TASK PERFORMANCE REQUIREMENTS

Aircraft Class (Task)	Class I	Class II	Class III
Cruise	Straight, Level Flight VFR, in turbulence generated by formation. Maintain altitude ±20 ft cruise speed ±5 kn heading and attitude ±5 deg.	Straight, Level Flight Same as Class I	Straight, Level Flight Same as Class I
	IFR flight. Maintain altitude ±50 ft airspeed ±5 kn heading and attitude ±5 deg.	IFR, in turbulence generated by formation. Maintain altitude ±20 ft airspeed ±5 kn heading and attitude ±5 deg.	Same as Class II
	3-deg/sec Turn Same as straight, level cruise except heading, yaw rate ±1 deg/sec.	3-deg/sec Turn Same as straight, level cruise except heading, yaw rate ±1/2 deg/sec.	3-deg/sec Turn Same as Class II
	Terrain Following, VFR. Gusts up to 20 kn, vertical gusts up to 20 ft/sec. Follow moderate terrain features (average ridge-to-valley distance 2400 ft, average slope 7.5 deg) within 20 to 100 ft at cruise speed, ±10 kn maintaining heading ±10 deg.	Terrain Following, VFR. Same as Class I	Terrain Following, VFR. Same as Class I
	Terrain Following, IFR. No requirement	Terrain Following, IFR. Gusts up to 20 kn, vertical gusts up to 20 ft/sec, with terrain-following equipment. Follow moderate terrain features within 50 to 200 ft at cruise speed, ±10 kn, maintaining heading ±5 deg.	Terrain Following, IFR. Same as Class II
	Nap-of-the-Earth Flight, VFR. No requirement	Nap-of-the-Earth Flight, VFR. Gusts up to 10 kn. At 80 kn ±10 kn, follow local terrain features with maneuvers from 0.5 to 2.5 g's, controlling flight path altitude ±10 ft, and heading ±5 deg.	Nap-of-the-Earth Flight, VFR Same as Class II

TABLE III - Continued

Aircraft Class (Task)	Class I	Class II	Class III
Climb	Climb, VFR. Acceleration at least 3 kn/sec heading and roll attitude ±5 deg rate of climb at least 500 fpm	Climb, VFR. Acceleration at least 5 kn/sec heading and roll attitude ±5 deg rate of climb at least 1000 fpm	Climb, VFR. Same as Class II
	Climb, IFR. Climb airspeed ±10 kn heading ±10 deg attitude ±5 deg rate of climb 1000 fpm, ±100 fpm	Climb, IFR. Climb airspeed ±10 kn heading ±10 deg attitude ±5 deg rate of climb 2000 fpm, ±100 fpm	Climb, IFR. Same as Class II
	500 fpm Climb. Same as straight, level flight except altitude. Rate of climb ±100 fpm	500 fpm Climb. Same as straight, level cruise except altitude. Rate of climb ±100 fpm	500 fpm Climb. Same as Class II
Descent	From cruise, establish a rate of descent of 500 fpm, ±100 fpm, attitude ±5 deg, airspeed ±10 kn, heading ±10 deg in ____ sec.	From cruise, establish a rate of descent of 1000 fpm, ±100 fpm, attitude ±5 deg, airspeed ±5 kn, heading ±5 deg in ____ sec.	Same as Class II
	Turn 3 deg/sec ±1 deg/sec at 500 fpm rate of descent, ±100 fpm, maintaining airspeed ±10 kn, attitude ±5 deg. Roll out at desired heading ±10 deg.	Turn 3 deg/sec ± 1/2 deg/sec at 1000 fpm rate of descent, ±100 fpm, maintaining airspeed ±10 kn, attitude ±5 deg. Roll out at desired heading ±5 deg.	Same as Class II
	Target Tracking No requirement	Target Tracking No requirement	Target Tracking (Gusts up to 10 kn, VFR). Maintain pitch attitude and heading ±2 deg, roll attitude ±5 deg, rate of descent ±100 fpm at rates of descent up to 1000 fpm.
	Target Acquisition No requirement	Target Acquisition No requirement	Target Acquisition (Gusts up to 10 kn, VFR) Stabilize change in heading of 20 deg in no more than 10 sec to allowances in target tracking

TABLE III - Continued

Aircraft Class (task)	Class I	Class II	Class III
Descent	Break off Maneuver. No requirement	Break off Maneuver. Change from 1000-fpm rate of descent, ±100 fpm, to 2000 fpm rate of climb, ±100 fpm, and change heading 180 deg, ±10 deg, at any airspeed above 60 kn in no more than 15 sec.	Break off Maneuver. Change from 1000-fpm rate of descent, ±100 fpm to 2000 fpm rate of climb, ±100 fpm, and change heading 180 deg, ±10 deg, at any airspeed above 60 kn in no more than 12 sec.
Acceleration	Accelerate to cruise speed ±10 kn at an average of at least 2 kn/sec, maintaining roll attitude ±5 deg, heading ±10 deg.	Accelerate to cruise speed ±10 kn at an average of at least 3 kn/sec, maintaining roll attitude ±5 deg, heading ±5 deg.	Accelerate to cruise speed ±10 kn at an average of at least 5 kn/sec, maintaining roll attitude ±5 deg, heading ±5 deg.
Deceleration	At least 3 kn/sec	At least 5 kn/sec	At least 8 kn/sec
Pullout	____ g at ____ kn	____ g at ____ kn	____ g at ____ kn
Reverse Direction of Flight	Maintain airspeed ±5 kn and altitude ±20 ft in a 3-deg/sec, ±1 deg/sec, turn.	Maintain airspeed ±3 kn and altitude ±20 ft in a 3-deg/sec, ±1/2 deg/sec, turn.	Same as Class II
	Establish a 15-deg/sec, ±3-deg/sec, turn rate in no more than 5 sec. Maintain airspeed ±10 kn and altitude within -20 to +50 ft.	Same as Class I	Same as Class I
Teardrop Maneuver	No requirement	From cruise, establish maximum rate of turn and pass over point of maneuver initiation, maintaining airspeed ±10 kn and altitude ±20 ft in no more than 30 sec.	From cruise, establish maximum rate of turn, maintaining airspeed ±10 kn and execute gunnery run on point of maneuver initiation in no more than 13 sec.
Gunnery Run	No requirement	No requirement	In gusts up to 10 kn, VFR and rates of descent from 0 - 1000 fpm, above 60 kn. Maintain pitch attitude and heading ±5 deg roll attitude ±5 deg rate of descent ±100 fpm

TABLE III - Continued

Aircraft Class (Task)	Class I	Class II	Class III
Autorotation Entry	Emergency, VFR. At any airspeed, up to V_{max}, establish engine-out rate of descent of 500 fpm, ±100 fpm. Maintain pitch and roll attitude ±5 deg, heading ±10 deg.	Emergency, VFR. Same as Class I	Emergency, VFR. Same as Class I
	Emergency, IFR. No requirement	Emergency, IFR. At any airspeed, up to V_{max}, establish engine-out rate of descent of 500 fpm, ±100 fpm. Maintain pitch and roll attitude ±5 deg, heading ±5 deg.	Emergency, IFR. Same as Class II

TABLE IV, HIGH SPEED FLIGHT, (120 kn to V_{max}), TASK PERFORMANCE REQUIREMENTS

Aircraft Class (Task)	Class I	Class II	Class III
Cruise	Straight, level cruise requirements same as low-speed flight.	Straight, level cruise requirements same as low-speed flight.	Straight, level cruise requirements same as low-speed flight.
	Terrain Following, VFR. Gusts up to 20 kn, vertical gusts up to 20 ft/sec. Follow moderate terrain features (average ridge-to-valley distance 2400 ft, average slope 7.5 deg) within 20 to 100 ft at cruise speed, ±10 kn, maintaining heading ±10 deg.	Terrain Following, VFR. Same as Class I	Terrain Following, VFR. Same as Class I
	Terrain Following, IFR. No requirement	Terrain Following, IFR. Gusts up to20 kn, vertical gusts up to 20 ft/sec, with terrain-following equipment. Follow moderate terrain features within 50 to 200 ft at cruise speed, ±10 kn, maintaining heading ±5 deg.	Terrain Following, IFR. Same as Class II
	Nap-of-the-Earth Flight No requirement	Nap-of-the-Earth Flight Gusts up to 10 kn, VFR. At 80 kn, ±10 kn, follow local terrain features with maneuvers from 0.5 to 1.5 g's, controlling flight path altitude ±10 ft, and heading ±5 deg.	Nap-of-the-Earth Flight Gusts up to 10 kn, VFR. At 80 kn, ±10 kn, follow local terrain features with maneuvers from 0.5 to 2.5 g's, controlling flight path altitude ±10 ft, and heading ±5 deg.
Climb at Cruise Speed	500 fpm Climb Maintain rate of climb ±100 fpm	500 fpm Climb Same as Class I	500 fpm Climb Same as Class I
	Stabilize a 100-ft change in altitude to ±20 ft in 10 sec, maintaining heading and roll attitude ±5 deg and airspeed ±5 kn.	Same as Class I	Same as Class I
Breakoff Maneuver	No requirement	Change from 500 fpm rate of descent, ±100 fpm, to 1000 fpm rate of climb, ±100 fpm, and change heading 180 deg ±5 deg at any speed above ____ kn in no more than ____ sec.	Change from 1000 fpm rate of descent, ±100 fpm, to 2000 fpm rate of climb, ±100 fpm, and change heading 180 deg ±5 deg at any speed above ____ kn in no more than ____ sec.

TABLE IV - Continued

Aircraft Class (Task)	Class I	Class II	Class III
Descent	From cruise, establish a rate of descent of 500 fpm, ±100 fpm, attitude ±5 deg, airspeed ±10 kn, heading ±10 deg in ___ sec.	From cruise, establish a rate of descent of 1000 fpm, ±100 fpm, attitude ±5 deg, airspeed ±5 kn, heading ±5 deg in ___ sec.	Same as Class II
	Turn 3 deg/sec, ±1 deg/sec, at 500-fpm rate of descent, ±100 fpm, maintaining airspeed ±10 kn, attitude ±5 deg. Roll out at desired heading ±10 deg.	Turn 3 deg/sec, ±1/2 deg/sec, at 1000-fpm rate of descent, ±100 fpm, maintaining airspeed ±10 kn, attitude ±5 deg. Roll out at desired heading ±5 deg.	Same as Class II
	Target-Tracking No requirement	Target-Tracking No requirement	Target Tracking (Gusts up to 10 kn, VFR). Maintain pitch attitude and heading ±2 deg, roll attitude ±5 deg, rate of descent ±100 fpm, at rates of descent up to 1000 fpm
	Target-Acquisition No requirement	Target-Acquisition No requirement	Target Acquisition (Gusts up to 10 kn, VFR). Stabilize change in heading of 90 deg in no more than 10 sec to allowances in target tracking.
Acceleration	Accelerate to cruise speed ±10 kn, at an average of at least 2 kn/sec maintaining roll attitude ±5 deg, heading ±10 deg.	Accelerate to cruise speed ±10 kn, at an average of at least 3 kn/sec maintaining roll attitude ±5 deg, heading ±5 deg.	Accelerate to cruise speed ±10 kn, at an average of at least 5 kn/sec maintaining roll attitude ±5 deg, heading ±5 deg.
Deceleration	At least 2 kn/sec	At least 4 kn/sec	At least 8 kn/sec
Reverse Direction of Flight	Maintain airspeed ±5 kn, and altitude ±20 ft in a 3-deg/sec, ±1 deg/sec, turn.	Maintain airspeed ±3 kn, and altitude ±20 ft in a 3-deg/sec, ±1/2 deg/sec, turn.	Same as Class II
	Establish a 15-deg/sec, ±3 deg/sec, turn rate in no more than 5 sec. Maintain airspeed ±10 kn and altitude within -20 to +50 ft.	Same as Class I	Same as Class I

TABLE IV - Continued

Aircraft Class (Task)	Class I	Class II	Class III
Reverse Direction	Change heading 180°, ±15 deg, in no more than 25 sec.	Change heading 180 deg, ±10 deg, in no more than 15 sec.	Change heading 180 deg, ±10 deg, in no more than 12 sec.
Tear Drop Maneuver	No requirement	From cruise, establish maximum rate of turn and pass over point of maneuver initiation, maintaining airspeed ±10 kn and altitude ±20 ft in no more than 30 sec.	From cruise, establish maximum rate of turn, maintaining airspeed ±10 kn, and execute gunnery run on point of maneuver initiation in no more than 13 sec.
Autorotation Entry	Emergency, VFR. At any airspeed. up to V_{max}, establish engine-out rate of descent of 500 fpm, ±100 fpm. Maintain pitch and roll attitude ±5 deg, heading ±10 deg.	Emergency, VFR. Same as Class I	Emergency, VFR. Same as Class I
	Emergency, IFR. No requirement	Emergency, IFR. At any airspeed up to V_{max}, establish engine-out rate of descent of 500 fpm, ±100 fpm. Maintain pitch and roll attitude ±5 deg, heading ±5 deg.	Emergency, IFR. Same as Class II
Assault Landing From Low-Altitude Cruise	No requirement	From cruise at altitude of 50 ft, ±10 ft, initiate landing flare 100 ft from desired landing spot. Touch down within 6 ft of desired landing spot, maintaining downwind heading ±5 deg. roll attitude ±5 deg, touch down at less than 5 ft/sec, sink rate and 0-to 10-kn ground speed. Maintain 50-ft aircraft separation, ±12 ft.	No requirement

PROPOSED SPECIFICATIONS FORMAT AND ITEMS FROM CURRENT SPECIFICATIONS APPLICABLE TO WINGED HELICOPTERS

In mission task performance oriented design specifications, a logical correlation of task performance requirements and specifications is essential. To provide for this, a new specifications format was developed. The format is in two parts: (1) airframe specifications, which deal with the mechanical aspects of the aircraft, and (2) flying qualities specifications. The airframe specifications are divided into sections which cover various aspects of airframe design. The flying qualities specifications are grouped under static and dynamic stability, which in turn are subdivided into flight regimes. This subdivision permits an easy reference for both the structural and aerodynamics designer, while providing an easy correlation with task performance through reference to flight regimes. The format should be expanded to include the requirements differences for the various winged helicopter classes, when the necessary data become available.

To evaluate current specifications as related to mission task performance requirements, a list of currently used and proposed specifications which are applicable to a winged helicopter was compiled. This was done by examining helicopter, V/STOL, and CTOL specifications and by listing the requirements which are applicable to winged helicopters. The currently used specifications considered were MIL-H-8501A and MIL-F-8785, and the proposed specifications were AGARD TR-408 and USAAVLABS TR 65-45. The selected requirements were listed under the appropriate items of the proposed specifications outline. Nonexistence of an applicable requirement for a particular item in one or all of the specifications considered was also indicated in the outline. The influence of these specifications upon an aircraft's mission task performance capability can be evaluated by correlating the aircraft's conformance to specifications listed with its task performance flight test data.

To facilitate the evaluation of an aircraft's conformance to the specifications listed, a Combined Specifications Conformance Evaluation Form was prepared. This was done by listing only the most stringent requirements under each item. Thus, if an aircraft meets the listed requirement, it meets or exceeds the other requirements. In cases of conflicting or incompatible requirements, all requirements in question were retained under the given item.

The currently used and proposed specifications requirements which can be applied to winged helicopters from MIL-H-8501A, MIL-F-8785, AGARD TR-408, and USAAVLABS TR 65-45, together with the proposed specifications format, are presented on the following pages.

PROPOSED SPECIFICATIONS FORMAT

1. **Airframe Specifications**

   1.1 Clearance Requirements

   1.1.1 Ground-Interference and Ground-Clearance
   1.1.2 Aircraft Component Separation and Clearance
   1.1.3 Armament Clearance Requirements

   1.2 Pilot Station

   1.2.1 Kinesthetic and Vestibular Cues
   1.2.2 Cockpit Visibility
   1.2.3 Instrument Layout
   1.2.4 Entry and Exit
   1.2.5 Armament Provisions

   1.3 Control System

   1.3.1 Type of Controls
   1.3.2 Control Layout
   1.3.3 Control Displacements
   1.3.4 Free Play in Controls
   1.3.5 Control Breakout Forces
   1.3.6 Armament Controls
   1.3.7 Avionics Controls

2. **Flying Qualities Specifications**

   2.1 Static Stability

   2.1.1 Longitudinal

   2.1.1.1 Hover and Vertical Flight
   2.1.1.2 Low-Speed Flight
   2.1.1.3 Transition
   2.1.1.4 High-Speed Flight
   2.1.1.5 Autorotation

   2.1.2 Lateral and Directional

   2.1.2.1 Hover and Vertical Flight
   2.1.2.2 Low-Speed Flight
   2.1.2.3 Transition

CURRENTLY USED AND PROPOSED SPECIFICATIONS

1. Airframe Specifications

1.1 Clearance Requirements

1.1.1 Ground Interference and Ground Clearance

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.1.2 Aircraft Component Separation and Clearance

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.1.3 Armament Clearance Requirements

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.2 Pilot Station

1.2.1 Kinesthetic and Vestibular Cues

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.2.2 Cockpit Visibility

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.2.3 Instrument Layout

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.2.4 Entry and Exit

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.2.5 Armament Provisions

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.3 Control System

1.3.1 Type of Controls

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	Stick type controls shall be used for VTOL aircraft

1.3.2 Control Layout

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.3.3 Control Displacements

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	Longitudinal control stick travel ±4 inches Lateral and directional control travel ±3 inches

USAAVLABS TR 65-45

Control	Type	Desired Travel (in.)	Max Travel (in.)
Longitudinal	Stick	±4	±6-1/2
Lateral	Stick	±3	±6-1/2
Directional	Pedal	±3	±3-1/2
Height	Lever	-	-
Throttle	Throttle	-	-

1.3.4 Free Play in Controls

MIL-H-8501A	No specifications
MIL-F-8785	Control free play shall not be excessive
AGARD TR-408	Free play shall not exceed ±1% of total control travel
USAAVLABS TR 65-45	Free play shall not exceed ±1% of total control travel or ±3% with boost system failure

1.3.5 Control Breakout Forces

MIL-H-8501A

Control	Limit Control Forces for Breakout, Including Friction (lbs)	
	Min	Max
Longitudinal	0.5	1.5
Lateral	0.5	1.5
Collective	1.0	3.0
Directional	3.0	7.0

MIL-F-8785

Control		Allowable Breakout Forces, Including Friction (lbs)			
		Fighter-Interceptor		Light, Transport, Bomber	
		Min	Max	Min	Max
Elevator	Stick	1/2	3	1/2	5
	Wheel	1/2	4	1/2	7
Aileron	Stick	1/2	2	1/2	4
	Wheel	1/2	3	1/2	6
Rudder	Pedals	1-1/2	7	1-1/2	14

AGARD TR-408

Control	Normal Operation (lbs)	After Failure of Appropriate Power Control Systems(lbs)
Longitudinal	0.5 to 2.5	Less than 5
Lateral	0.5 to 2.0	Less than 4
Directional	1.0 to 10.0	Less than 15
Height-Stick	1.0 to 3.0	Less than 5
Throttle	1.0 to 3.0	Less than 3

USAAVLABS TR 65-45

Control	Normal Operation (lbs)	After Power Control Failure (lbs)
Longitudinal	0.5 to 2.5	Less than 5
Lateral	0.5 to 2.0	Less than 4
Directional	1.0 to 10.0	Less than 15
Height	Adjustable Friction Desirable	
Lever	1.0 to 3.0	Less than 5
Throttle	1.0 to 3.0	Less than 3

1.3.6 Armament Controls

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

1.3.7	Avionics Controls	No specifications

2. Flying Qualities Specifications

2.1 Static Stability

2.1.1 Longitudinal

2.1.1.1 Hover and Vertical Flight

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.1.1.2 Low-Speed Flight

MIL-H-8501A	The helicopter shall possess positive static control force and control position stability.
MIL-F-8785	a. Elevator-fixed neutral point shall be aft of the C.G. b. Elevator-fixed static stability with respect to angle of attack at constant speed shall be positive. c. Elevator-free neutral points shall be aft of the C.G.
AGARD TR-408	The aircraft should possess positive control position and control force stability with respect to speed.
USAAVLABS TR 65-45	The aircraft shall possess positive control position and control force stability with respect to speed for all steady-flight conditions.

2.1.1.3 Transition

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.1.1.4 High Speed Flight

MIL-H-8501A	The helicopter shall possess positive static force and control position stability.
MIL-F-8785	a. Elevator-fixed neutral point shall be aft of the C.G. b. Elevator-fixed static stability with respect to angle of attack at constant speed shall be positive. c. Elevator-free neutral points shall be aft of the C.G.
AGARD TR-408	The aircraft should possess positive control position and control force stability with respect to speed.
USAAVLABS TR 65-45	The aircraft shall possess positive control position and control force stability with respect to speed for all steady-flight conditions.

2.1.1.5 Autorotation

MIL-H-8501A	No specifications
MIL-F-8785	No specifications

AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.1.2 Lateral and Directional

2.1.2.1 Hover and Vertical Flight

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.1.2.2 Low-Speed Flight

MIL-H-8501A	The helicopter shall possess positive control-fixed directional stability and effective dihedral.
MIL-F-8785	The aircraft shall possess rudder-fixed directional stability such that right rudder pedal deflection from wings-level position is required in left sideslips, and left rudder pedal deflection is required for right side-slip.
AGARD TR-408	Same as MIL-F-8785
USAAVLABS TR 65-45	The aircraft shall demonstrate control position and control force stability; that is, increasing left directional control motion, force, and bank angle shall be required to produce an increasing right sideslip, and vice versa. For angles of sideslip between +15 and -15 degrees, the variation of sideslip angle with lateral and directional control motion shall be essentially linear.

2.1.2.3 Transition

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	The change in stick position with change in speed should not exceed 0.1 inch per knot in normal operation, and 0.25 inch per knot in emergency operation.
USAAVLABS TR 65-45	With maximum forward acceleration, the rate of stick movement to maintain trim should not exceed 1/2 inch per second and shall not exceed 1 inch per second.

2.1.2.4 High-Speed Flight

MIL-H-8501A	The helicopter shall possess positive control-fixed directional stability and effective dihedral.
MIL-F-8785	The aircraft shall possess rudder-fixed directional stability such that right rudder pedal deflection from wings-level position is required in left sideslips, and left rudder pedal deflection is required for right sideslips.
AGARD TR-408	Same as MIL-F-8785
USAAVLABS TR 65-45	The aircraft shall demonstrate control position and control force stability; that is, increasing left directional control motion, force, and bank angle shall be required to produce an increasing right sideslip, and vice versa. For angles of sideslip between +15 and

			-15 degrees, the variation of sideslip angle with lateral and directional control motion shall be essentially linear.
2.1.2.5	Autorotation		
		MIL-H-8501A	The helicopter shall possess positive control-fixed directional stability and effective dihedral.
		MIL-F-8785	No specifications
		AGARD TR-408	No specifications
		USAAVLABS TR 65-45	No specifications
2.2	Dynamic Stability		
2.2.1	Longitudinal		
2.2.1.1	Hover and Vertical Flight		
		MIL-H-8501A	Pitch angular velocity damping shall be at least $8I_y^{0.7}$ ft/-lb/rad/sec
		MIL-F-8785	No specifications
		AGARD TR-408	Pitch velocity damping must conform to Figure 2
		USAAVLABS TR 65-45	No specifications
2.2.1.2	Low-Speed Flight		
		MIL-H-8501A	a. Oscillations of periods of less than 5 seconds shall damp to 1/2 amplitude in not more than two cycles. b. Oscillations of periods between 5 and 10 seconds shall be at least lightly damped. c. Oscillations of periods between 10 and 20 seconds shall not achieve double ampli-

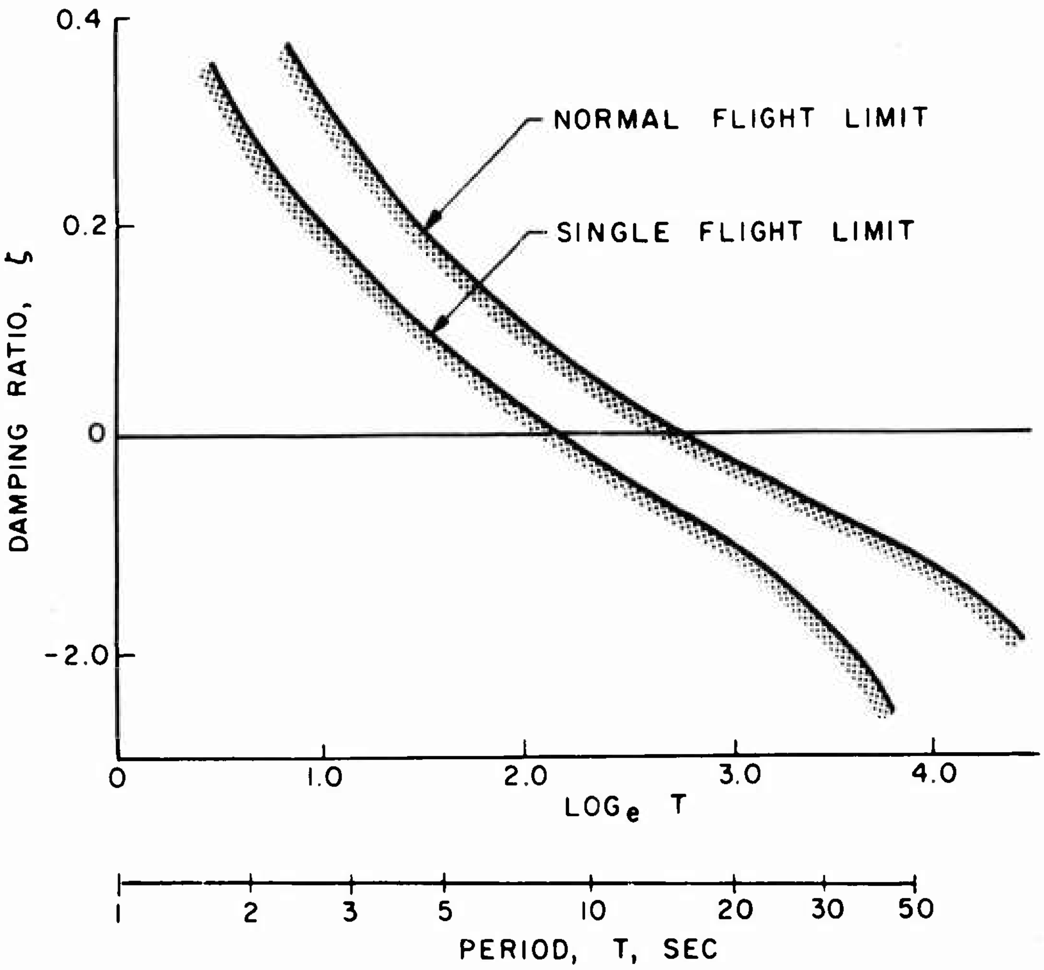

Figure 2. Longitudinal Response Characteristics Requirements, AGARD TR-408, Figure 2.

		tude in less than 10 seconds.
	d.	After a sudden control displacement, sufficient to produce 0.2-rad/sec pitching rate within 2 seconds, or a normal acceleration of 1.5 g's within 3 seconds, whichever is less, the time history of normal acceleration shall become concave downward within 2 seconds and shall remain concave downward until maximum angular velocity is attained.
MIL-F-8785	a.	Oscillations of periods of less than 6 seconds must damp to 1/2 amplitude in one cycle.
	b.	Oscillations of periods of less than 15 seconds shall be at least neutrally stable.
AGARD TR-408	a.	Pitch velocity damping must be at least as specified in Figure 2.
	b.	After a sudden rearward longitudinal control displacement, sufficient to generate a 0.2-rad/sec pitch rate, or a normal acceleration of 1.2 g's within 3 seconds, the time history of normal acceleration should become concave downward within 2 seconds following the control input and should remain convave downward, with the stick fixed,

		until maximum acceleration is attained.
	USAAVLABS TR 65-45	Pitch velocity damping must conform to Figure 3.
2.2.1.3	Transition	
	MIL-H-8501A	No specifications
	MIL-F-8785	No specifications
	AGARD TR-408	a. Constant altitude transition. b. Transition must be reversible.
	USAAVLABS TR 65-45	Same as AGARD TR-408
2.2.1.4	High-Speed Flight	
	MIL-H-8501A	a. Oscillations of periods of less than 5 seconds shall damp to 1/2 amplitude in not more than two cycles. b. Oscillations of periods between 5 and 10 seconds shall be at least lightly damped. c. Oscillations of periods between 10 and 20 seconds shall not achieve double amplitude in less than 10 seconds. d. After a sudden control displacement, sufficient to produce a 0.2-rad/sec pitching rate within 2 seconds, or a normal acceleration of 1.5 g's within 3 seconds, whichever is less, the time history of normal acceleration shall become concave downward within 2 seconds and shall remain concave downward until

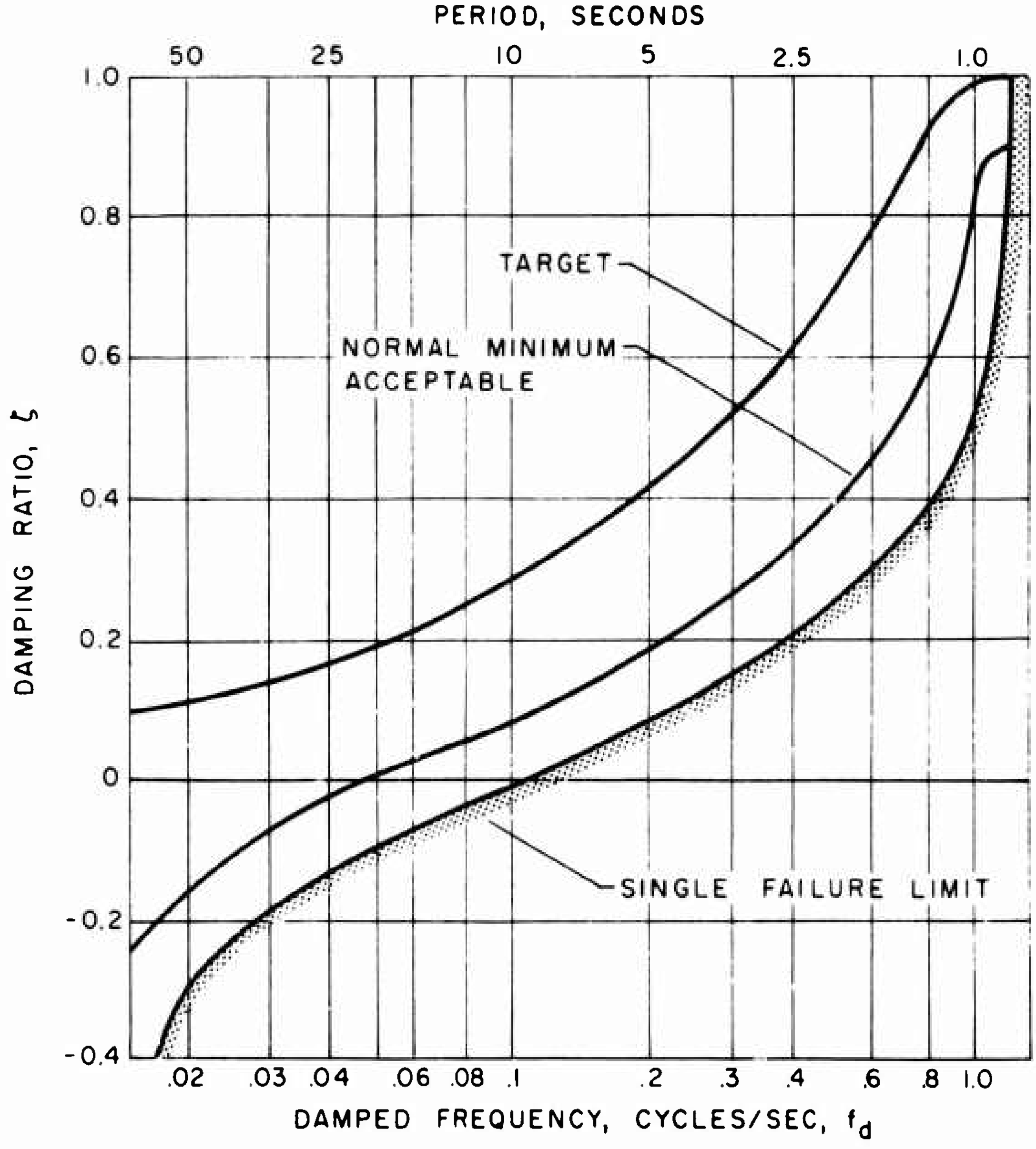

Figure 3. Damping Characteristics Versus Frequency, USAAVLABS TR 65-45, Figure 1.

	maximum angular velocity is attained.
MIL-F-8785	a. Oscillations of periods of less than 6 seconds must damp to 1/2 amplitude in one cycle. b. Oscillations of periods of less than 15 seconds shall be at least neutrally stable.
AGARD TR-408	a. After a sudden rear-ward longitudinal control displacement, sufficient to generate a 0.2-rad/sec pitch rate, or a normal acceleration of 1.2 g within 3 seconds, the time history of normal acceleration should become concave down-ward within 2 seconds following the control input and should re-main concave down-ward, with the stick fixed, until maximum acceleration is attain-ed. b. During the above maneuver, the time history of angular velocity should become concave downward within 2 seconds until maximum angular velocity is attained.
USAAVLABS TR 65-45	For all permissible for-ward speeds and loadings, longitudinal oscillation with controls fixed, following a single distur-bance in smooth air, shall possess damping characteristics in accor-dance with Figure 3.

2.2.1.5 Autorotation		
	MIL-H-8501A	a. It shall be possible to make satisfactory, safe landings on a level, paved surface up to ground speeds of 35 knots. b. The aircraft shall be capable of entering into power-off autorotation at all speeds from hover to maximum forward speed. The transition from powered flight to autorotative flight shall be established smoothly with adequate controllability and with a minimum loss of altitude. It shall be possible to make this transition safely when initiation of the necessary manual collective-pitch control motion has been delayed for at least 2 seconds following loss of power. At no time during this maneuver shall the rotor speed fall below a safe minimum transient autorotative value.
	MIL-F-8785	No specifications
	AGARD TR-408	No specifications
	USAAVLABS TR 65-45	a. The aircraft shall be capable of power-off landings at touchdown speeds of no greater than 25 knots, with 15 knots or less as the desired touchdown speed.

b. The aircraft shall be capable of entry into autorotation at all speeds to V_{con}. A delay of 1 second following power failure prior to pilot corrective action is mandatory, and a delay of 2 seconds is desired. During the delay, no dangerous flight conditions (such as low main rotor rpm, lack of control, and transient aircraft attitudes) shall be encountered. With controls fixed for 2 seconds following sudden complete loss of power, roll, pitch, or yaw attitude changes shall not exceed 10 degrees.

2.2.2 Lateral and Directional

2.2.2.1 Hover and Vertical Flight

MIL-H-8501A	a. Roll angular velocity damping shall be at least 18 $I_X^{0.7}$ ft-lb/rad/sec. b. Yaw angular velocity damping shall be at least 27 $I_Z^{0.7}$ ft-lb/rad/sec.
MIL-F-8785	No specifications
AGARD TR-408	Roll-yaw velocity damping shall conform to Figure 2.
USAAVLABS TR 65-45	Lateral-Directional velocity damping shall conform to Figure 4.

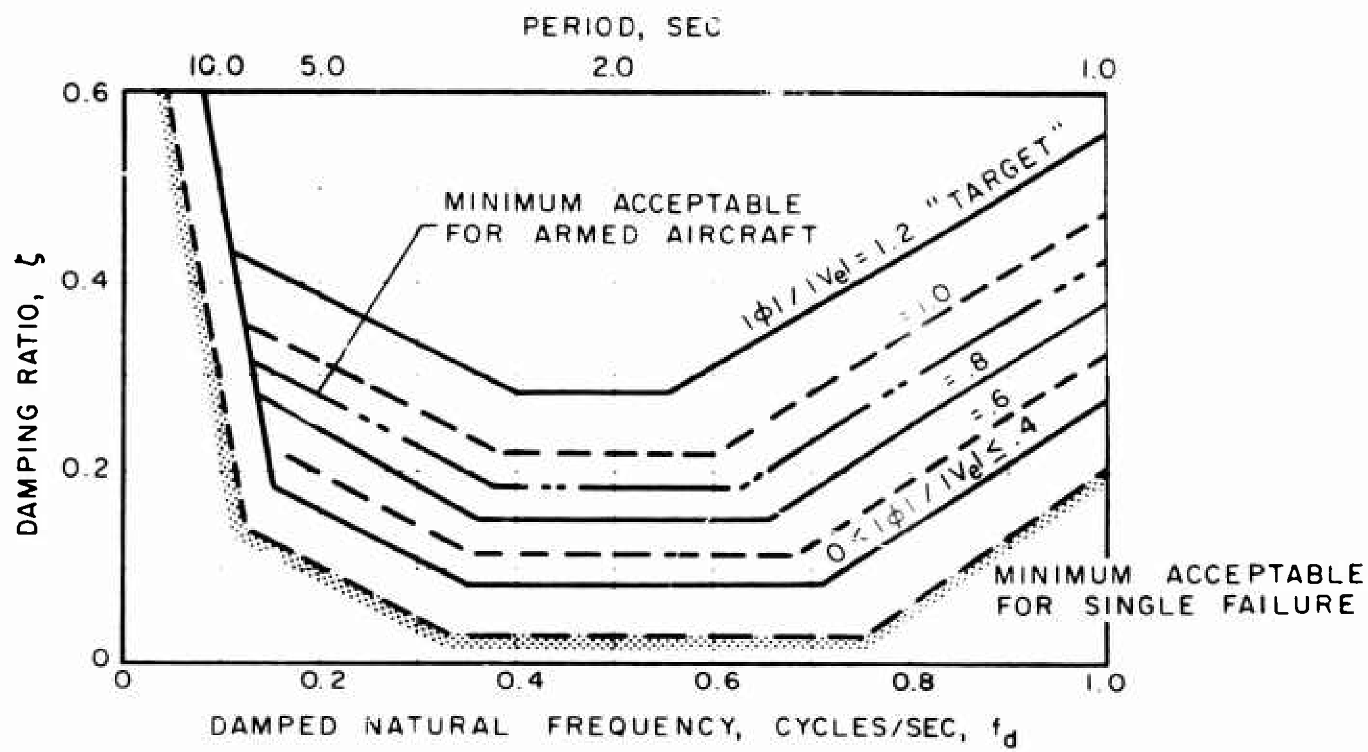

Figure 4. Lateral-Directional Requirements, USAAVLABS TR 65-45, Figure 3.

2.2.2.2 Low-Speed Flight

MIL-H-8501A		It shall be possible to obtain steady, level translational flight at a sideward velocity of at least 35 knots, in either direction.
MIL-F-8785	a.	The damping of lateral-directional oscillations, with controls fixed and with controls free, shall be such that the damping has a value of not less than that required by curve A of Figure 5. For class III aircraft, it should be at least as stated above, or 1.73, whichever is higher.
	b.	Spiral instability should not be so great that a small disturbance in bank angle, with controls fixed, doubles the bank angle in less than 20 seconds.
AGARD TR-408	a.	Lateral-directional oscillations shall exhibit the same characteristics as the longitudinal oscillations.
	b.	Spiral instability shall not be so great that, when controls are released in a steady 10-degree banked turn, the bank angle is doubled in less than 20 seconds.
USAAVLABS TR 65-45	a.	Lateral-directional oscillations with controls fixed shall have damping characteristics corresponding to

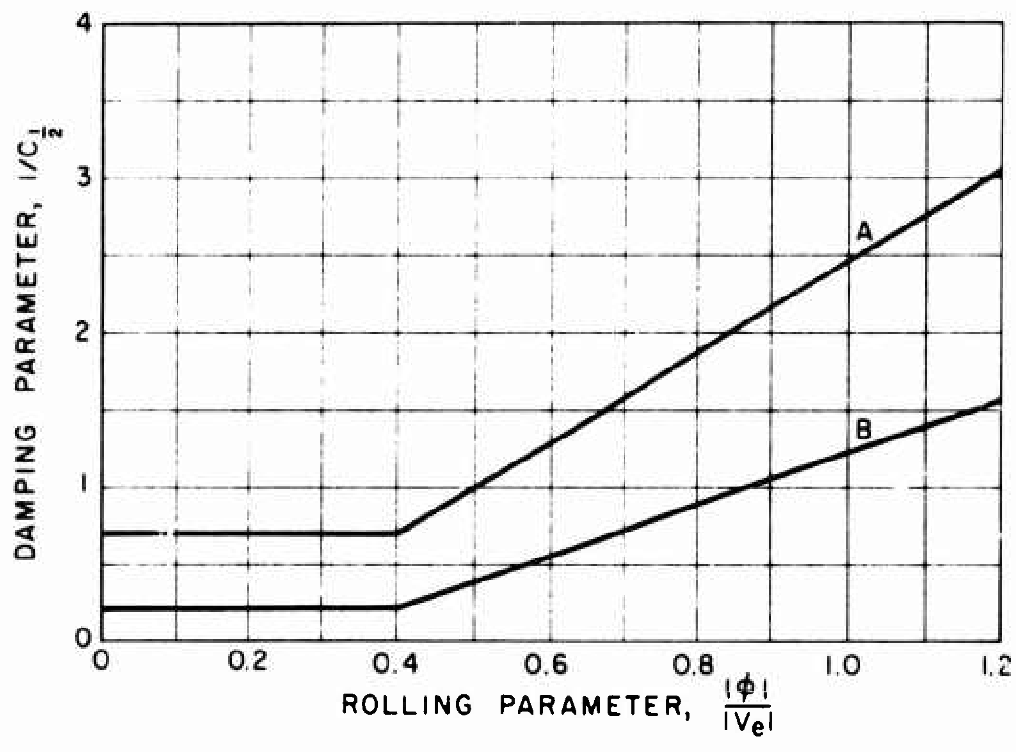

Figure 5. Lateral-Directional Damping Requirements, MIL-F-8785, Figure 1.

the curves in Figure 4.

b. Spiral instability shall not be so great that the bank angle doubles in less than 20 seconds when the controls are released in a steady 10-degree banked turn.
c. The angle of sideslip developed during an abrupt rudder-pedal fixed roll from a trimmed, level, steady 30-degree banked turn to a bank angle of 30 degrees in the opposite direction, without checking, should not exceed 15 degrees.

2.2.2.3 Transition

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.2.2.4 High-Speed Flight

MIL-H-8501A — No specifications

MIL-F-8785

a. The damping of lateral-directional oscillations, with controls fixed and with controls free, shall be such that the damping has a value of not less than that required by curve A in Figure 5. For class III aircraft, it should be at least as stated above, or 1.73, whichever is higher.
b. Spiral instability should not be so great that a small disturbance

		in bank angle with controls fixed doubles the bank angle in less than 20 seconds.
	AGARD TR-408	a. Lateral-directional oscillations shall exhibit the same characteristics as the longitudinal oscillations. b. Spiral instability shall not be so great that, when controls are released in a steady 10-degree banked turn, the bank angle is doubled in less than 20 seconds.
	USAAVLABS TR 65-45	a. Lateral-directional oscillations with controls fixed shall have damping characteristics corresponding to the curves in Figure 4. b. Spiral instability shall not be so great that the bank angle doubles in less than 20 seconds when the controls are released in a steady 10-degree banked turn. c. The angle of sideslip developed during an abrupt rudder-pedal fixed roll from a trimmed, level, steady 30-degree banked turn to a bank angle of 30 degrees in the opposite direction, without checking, should not exceed 15 degrees.
2.2.2.5	Autorotation	
	MIL-H-8501A	It shall be possible to

	make coordinated turns in each direction while in autorotation, at all autorotation speeds.
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	a. The aircraft shall be capable of entry into autorotation at all speeds to V_{con}. A delay of 1 second following power failure prior to pilot corrective action is mandatory, and a delay of 2 seconds is desired. During the delay, no dangerous flight conditions (such as low main rotor rpm, lack of control, and transient aircraft attitudes) shall be encountered. With controls fixed for 2 seconds following sudden complete loss of power, roll, pitch, or yaw attitude changes shall not exceed 10 degrees. b. While in autorotation at any speed, the longitudinal, lateral, and directional dynamic stability shall be essentially unchanged from those in powered flight with similar auxiliary equipment operating, such as control boost and autostabilization.

2.3 Control System

2.3.1 Aircraft Response Characteristics

2.3.1.1 Longitudinal

MIL-H-8501A

a. Adequate control to produce 10% of the maximum attainable pitching moment in hover shall be available in both directions at all trim conditions and speeds including autorotative flight.
b. The angular acceleration shall be in the proper direction within 0.2 second after control displacement.
c. A rapid 1-inch step displacement of the longitudinal control shall produce an angular displacement of at least $\frac{45}{\sqrt[3]{W+1000}}$ deg at the end of 1 second.
d. A rapid maximum control displacement shall produce an angular displacement of at least $\frac{180}{\sqrt[3]{W+1000}}$ deg at the end of 1 second.

MIL-F-8785

No specifications

AGARD TR-408

a. Angular accelerations shall be in the proper direction 0.2 sec after control application.
b. In forward flight, the aircraft shall possess at least the control and damping available in hovering flight.
c. A rapid full control deflection shall produce an angular displacement

of at least $\frac{300}{\sqrt[3]{W+1000}}$ deg in the first second.

d. A rapid 1-inch control deflection shall produce an angular displacement of at least $\frac{100}{\sqrt[3]{W+1000}}$ degrees in the first second.

USAAVLABS TR 65-45 a. After abrupt control inputs (step and pulse) of magnitudes sufficient to cover up to 80-percent design flight envelope limits (the minimum shall be that required to produce 5.0 degrees per second or Δn of 1.0 g, whichever occurs last), the aircraft shall meet the following conditions:

1. Less than 0.4 second to reach 0.5 deg/sec pitching velocity or .01 g (target, 0.1 second).
2. Time to reach 63% of steady-state value or 63% of initial peak for oscillatory modes shall be between 0.1 and 1.0 second (target, 0.3 second).
3. Time to reverse response for a pulse longitudinal stick input to the specified value in opposite direction shall be 0.4 second to reach 0.5 deg/sec pitching or .01 g (target, 0.1 second).

2.3.1.2 Lateral and Directional

MIL-H-8501A	a. At least 10% of the maximum attainable rolling moment in hover shall be available in both directions at all trim conditions and speeds. b. The control effectiveness is excessive if maximum rate of roll per inch of stick displacement is greater than 20 degrees per second. c. The angular acceleration shall be in the proper direction within 0.2 second after control displacement.
MIL-F-8785	a. On multiengined airplanes, with the critical engine failed, it shall be possible to maintain straight flight with a bank angle not greater than 5 degrees. b. The aircraft shall be capable of attaining roll parameter, $\frac{pb}{2V}$ values of .015 for light airplanes, horizontal bomber, cargo, etc., and .05 for fighter-interceptor types.
AGARD TR-408	a. The aircraft shall possess at least the control and damping available in hover in forward flight. b. A full lateral control displacement shall produce at least 10

	degrees of roll in the first second. c. Response to a rapid full control deflection shall be at least $\frac{200}{\sqrt[3]{W+1000}}$ degrees of roll in the first second. d. A rapid 1-inch control deflection shall produce at least $\frac{100}{\sqrt[3]{W+1000}}$ degrees of roll in the first second. e. A margin of at least 50% of the nominal control moment must be available at all trim conditions. f. The angular acceleration shall be in the proper direction 0.2 second after control application.
USAAVLABS TR 65-45	After abrupt control inputs (step and pulse) of magnitudes sufficient to cover up to 80% of design flight envelope limits; 1. Time to reach 0.5 degree per second rolling velocity, 0.5 second (target 0.1). 2. Time to reach 63% of steady-state value initially or 63% of initial peak for oscillatory modes, between 0.1 and 1.3 seconds (target, 0.25 second). 3. Time to reverse response for a pulse lateral stick input, to the specified value in the opposite

direction shall be 0. 3 second (target, 0. 1 second).

4. Time to reach a 1. 0-degree-per-second yaw rate, or β = 0. 5 degree, whichever comes first, 0. 3 second.
5. Time to reach 63% of steady-state value initially or time to reach 63% of initial peak for oscillatory modes between 0. 1 and 1. 5 seconds (target, 0. 5 second).

2. 3. 2 Control Force Characteristics

MIL-H-8501A

a. Cyclic stick force gradient for the first inch of travel from trim shall be no less than 0. 5 pound and no more than 2. 0 pounds per inch. The force produced for 1-inch of stick travel shall be no less than the breakout force.
b. The directional control shall have a limit force of 15 pounds at maximum deflection with a linear force gradient from trim.
c. Limit Control Forces

Control	Limit Control Force (lbs)
Longitudinal	8. 0
Lateral	7. 0
Collective	7. 0
Directional	15. 0

MIL-F-8785

a. Elevator control force gradient limit, lbs per g.

Class	Min	Max
Fighter-Interceptor	$\frac{21}{n_L - 1}$	$\frac{56}{n_L - 1}$
Light, Cargo, Horiz. Bomber	$\frac{45}{n_L - 1}$	$\frac{120}{n_L - 1}$

where n_L is limit load factor.

b. Lateral gradient shall be such that peak values of rates can be reached with not more than 25 lbs stick force or 50 lbs wheel force.

c. Rudder pedal control forces shall not exceed 180 lbs.

AGARD TR-408

a. Longitudinal and lateral control force gradients shall be between 1 and 2.5 lbs per inch.

b. Directional control force gradient shall be between 5 and 15 lbs per inch.

c. With a power control system failure, the control forces shall not exceed 40 lbs longitudinally, 20 lbs laterally, and 80 lbs directionally.

USAAVLABS TR 65-45

a. Control forces shall be in the ratio of 2:5:1 for longitudinal, directional, and lateral forces, respectively. The ratio of longitudinal to lateral shall not be less than 1:1 or more than 4:1. Directional to lateral shall not be less than 4:1 or more than 8:1.

b. Beyond the breakout region, the slope of the curve of control force versus displacement shall be positive at all times. The slope for the first 10% of travel from trim shall be greater than, or equal to, the slope for the remaining control travel; however, the change in slope shall not exceed 50%.

c. Limit forces

Forces to go from one trim condition to another shall not exceed:

Forces (lbs)

Control	Normal			After Failure		
	Hover	STOL	Cruise	Hover	STOL	Cruise
Longitudinal	10	30	40	20	40	50
Lateral	7	15	20	15	20	25
Directional	30	75	100	40	100	125

2.3.3 Vertical Thrust Margins

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	The out-of-ground-effect thrust available shall be at least 1.05 times the G.W. at takeoff, and 1.15 times G.W. at landing.
USAAVLABS TR 65-45	Same as AGARD TR-408.

2.3.4 Vertical Thrust Response

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.3.5 Height Control and Precision Hover

MIL-H-8501A	It shall be possible to keep the aircraft over a given point on the ground, for all terrain clearances and with winds up to 3 knots, with less than ±1.0-inch movement of cyclic controls.
MIL-F-8785	No specifications
AGARD TR-408	a. It should be possible to control vertical speed within ±1 ft/sec in all vertical flight conditions with less than ±1/2-inch movement of the vertical control. b. With power control or stability augmentation system failure, it should be possible to control vertical speed within ±2 ft/sec, while hovering in still air in ground effect. c. It should be possible to hover continuously, in the designated wind condition at any height up to the disappearance of ground effect, while any chosen point on the aircraft remains within a circle of 3 ft radius, without acquiring a velocity in excess of 2 ft/sec in any horizontal direction, and without requiring undue pilot skill or effort. Following a failure in a power control or stability

		augmentation system, it should be possible for a pilot of average skill to maintain the same precision during a typical vertical landing.
	USAAVLABS TR 65-45	a. It should be possible to control vertical speed within ±1 ft/sec in all vertical flight conditions with less than ±1/2-inch movement of the vertical control. b. Same as c. in AGARD TR-408.
2.3.6	Effect of Deceleration Devices	
	MIL-H-8501A	No specifications
	MIL-F-8785	a. Operation of speed brakes or other drag devices provided for deceleration shall not produce objectionable buffet or other undesirable flight characteristics. b. Longitudinal trim changes caused by drag device operation shall not be so large that peak longitudinal control forces in excess of 10 lbs for Class III aircraft or 20 lbs for Class I and Class II aircraft are required.
	AGARD TR-408	No specifications
	USAAVLABS TR 65-45	All aircraft shall be capable of deceleration, dive speed limitation, constant speed, and

		glide path control to any degree desired by the pilot, within limits that shall be stated in the contract or otherwise agreed to by the procuring activity.
2.3.7	Roll-Pitch-Yaw Coupling	
	MIL-H-8501A	No specifications
	MIL-F-8785	No specifications
	AGARD TR-408	a. The effects of engine, fan, or rotor gyroscopic moments on the dynamic behaviour of the aircraft should not result in objectionable flight or ground handling characteristics. In flight, the elimination of the cross-coupled response during any demonstration maneuver should require less than 20% (preferably less than 10%) of the nominal control moment about the cross-coupled axis. b. The application of any roll control input necessary to satisfy roll control recommendations, the other controls being held fixed, should not result in yaw motion, sideslip, or pitch attitude change which causes objectionable or dangerous flight conditions.
	USAAVLABS TR 65-45	In rudder and elevator cockpit control-fixed rolls through 360 degrees at all altitudes and permissible speeds, entered from straight flight, turns, pushovers, or pull-ups ranging from zero g to

		2/3 limit N. L. F., the resulting yaw motion, side-slip angle, and normal acceleration shall neither exceed structural limits nor cause other dangerous flight conditions, such as uncontrollable oscillations. During combat-type maneuvers involving similar rolls through angles of up to 180 degrees, the extent of the pitching and yawing shall not be so severe as to impair seriously the tactical effectiveness of the maneuver.
2. 4	Spin Characteristics	
	MIL-H-8501A	No specifications
	MIL-F-8785	The normal controls shall be adequate to provide consistent prompt recoveries from fully developed erect and inverted spins. Recovery shall require no abnormal effort on the part of the pilot.
	AGARD TR-408	At any possible flight condition appropriate to the type of operation, there should be no tendency for the aircraft to spin following the attainment of stalled conditions on the lifting surfaces, either during normal operation or after a single failure.
	USAAVLABS TR 65-45	Same as AGARD TR-408
2. 5	Stall Characteristics	
	MIL-H-8501A	No specifications

MIL-F-8785

a. Although it is desired that no nose-up pitch occur at the stall, a mild nose-up pitch may be accepted, provided that no dangerous or seriously objectionable flight conditions result. The stall shall be considered unacceptable if the airplane exhibits uncontrollable rolling or downward pitching at the stall in excess of 20 degrees from level for Classes I and II aircraft, or 30 degrees from level for Class III aircraft.

b. It shall be possible to prevent the complete stall by normal use of the controls at the onset of the stall warning. In the event of a complete stall, it shall be possible to recover by normal use of the controls with reasonable control forces, and without excessive loss of altitude or buildup of speed.

AGARD TR-408

a. The stalling of lifting surfaces should produce mild nose-down pitching (not more than 10 degrees change in attitude in 3 seconds with fixed controls), moderate settling of the aircraft (less than 0.2 g reduction in normal acceleration) and mild or moderate buffet (that which does not cause the pilot concern for the control or structural integrity of the aircraft). Unintended lateral attitude or heading changes at the stall are undesirable but, if they can not be prevented, the changes with controls fixed should not exceed 20 degrees in roll or 10 degrees in yaw within 3 seconds following the stall onset. If undamped oscillations occur, about any axis, that are of large enough amplitude to be of concern from the standpoint of aircraft control, they should be no shorter than 5 seconds in period. Prompt recovery from the stalled conditions should be possible by normal use of controls, including power, without excessive altitude loss with average pilot skill.

USAAVLABS 65-45	It is desired that no nose-up pitch occur at stall; however, a mild nose-up pitch may be acceptable if it does not result in any dangerous characteristics. It shall be possible to control the aircraft about all axes by normal use of controls down to stall. The stall shall be unacceptable if, at the stall, the aircraft exhibits uncontrollable rolling, yawing, or downward pitch in excess of 25 degrees or if there is any reversal of controls. It shall be possible to prevent stall by normal use of the controls at the onset of stall warning. In the event of a

		complete stall, it shall be possible to recover (by normal use of controls with reasonable control forces) without excessive loss of altitude or buildup of speed.
2.6	Effects of Armaments	
	MIL-H-8501A	No specifications
	MIL-F-8785	Operation of bomb bay doors, armament pods, other movable protuberances, or firing of weapons shall not cause objectionable buffet, trim changes, or other characteristics which impair the tactical effectiveness of the airplane under any flight condition in which operation of such devices may be required in the conduct of the airplane's mission.
	AGARD TR-408	No specifications
	USAAVLABS TR 65-45	Additional stability and control requirements, as necessary, shall be provided by the procuring agency to ensure characteristics acceptable for the mission of the aircraft being procured. In general, expending and/or operating the armament items shall not produce changes, such as trim, acceleration, attitude, or speed, that prevent effective utilization of the armament item. Blast and vibration due to armament operation shall not be objectionable to or uncomfortable for the crew, as determined by the procuring agency.

Engine operations shall not be affected adversely under any condition by armament operation.

2.7	Vibration Characteristics	
	MIL-H-8501A	a. Vibration accelerations at all controls in any direction shall not exceed 0.4 g for frequencies up to 32 cps and a double amplitude of .008 inch for frequencies above 32 cps. b. Vibration accelerations at the pilot, crew, passenger, and litter stations shall not exceed 0.15 g for frequencies up to 32 cps and a double amplitude of .003 inch for frequencies greater than 32 cps. From V_{cruise} to V_{limit}, the maximum vibratory acceleration shall not exceed 0.2 g up to 36 cps and a double amplitude of .0036 inch for frequencies greater than 36 cps. Above 50 cps, a constant velocity vibration of .039 fps shall not be exceeded. c. Vibration accelerations at the pilot, crew, passenger, and litter stations shall not exceed 0.3 g up to 44 cps and a double amplitude of .003 inch at frequencies greater than 44 cps during acceleration or deceleration.
	MIL-F-8785	No specifications

AGARD TR-408	No specifications
USAAVLABS TR 65-45	Same as MIL-H-8501A

2.8 General Requirements

2.8.1 Speed Stability

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.8.2 Tail Rotor Failure

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	a. Following complete loss of the antitorque tail rotor and tail rotor gearbox, the aircraft shall not pitch uncontrollably. Sufficient longitudinal control shall be available to allow safe flight with the weight of the tail rotor and gearbox removed. b. The aircraft shall have sufficient directional stability with the tail rotor off, to fly at a speed for the minimum power required at maximum gross weight, with zero tail rotor thrust, at a sideslip angle of no greater than 20 degrees. c. The aircraft shall be capable of making a power-off landing at a speed that is no greater than 35 knots, and preferably less, without turnover, on a level sod surface, with zero tail rotor thrust.

2.8.3 Forward Propulsion System Failure

MIL-H-8501A	No specifications
MIL-F-8785	a. On multiengine airplanes, the airplane motions following sudden failure of one engine shall be such that dangerous flight conditions can be avoided by normal pilot corrective control action. As a measure of compliance with this requirement, the following conditions shall be fulfilled: In configuration P, with the most critical engine inoperative (with rpm and pitch simulating the static condition after an engine has failed in flight with no corrective action unless automatically provided), and with the other engine or engines developing normal rated power, it shall be possible at all speeds, with rudder free, to maintain steady straight flight by sideslipping and banking. The weight shall be that corresponding to the lightest normal service loading, and trim shall be as required for wings-level straight flight with symmetric power. b. On all multiengine airplanes in configuration TO with the most critical

outboard engine inoperative (with rpm and pitch simulating failure in flight with no corrective action unless automatically provided), it shall be possible, at the lightest normal takeoff loading and with takeoff power on the remaining engine, or engines, to maintain straight flight with a bank angle not greater than 5 degrees, at all speeds above $1.2V_{STO}$. Automatic devices which normally operate in the event of power failure may be used. With trim settings normally employed in a symmetric power takeoff, the rudder pedal force required to maintain straight flight with asymmetric power, as defined above, shall not exceed 180 lb.

AGARD TR-408

a. Single-Engined Aircraft. To ensure that the pilot has time to escape following engine failure of a single-engine V/STOL aircraft, the attitude changes in roll and pitch should not exceed 20 degrees in the first 3 seconds following the failure, the controls being free during this period.
b. Multi-Engined Aircraft. Following failure of the critical engine of a multi-engined aircraft it should be possible to recover at

all speeds up to V_{con}, assuming normal pilot reaction capability. After recovery, margins of control power in the critical direction at least equal to those in the following Table should remain at all speeds up to V_{con}. These margins should remain available throughout the approach and landing.

Control margins remaining after critical engine failure	
Longitudinal	20 per cent of the nominal control moment available before the failure.
Lateral	50 per cent of the roll control moment specified before power failure.
Directional	For STOL. 20 per cent of the nominal control moment available before the failure. For VTOL a response of $60/(W + 1000)^{1/3}$ degrees in the first second.

USAAVLABS TR 65-45

a. Single-Engine Aircraft - To ensure that the pilot has time to escape following engine failure of a single-engine V/STOL aircraft or that he can accomplish an immediate emergency landing in a near-wings and fuselage-level attitude, the attitude changes in roll and pitch should not exceed 20 degrees in the first 3 seconds following the failure, the controls being free during this period.

b. Multiengine Aircraft - Following failure of the critical engine of a multiengine aircraft, it is desirable that recovery be possible at all speeds up to V_{con}. However, the minimum acceptable conditions shall be those in an emergency landing in a near-wings and fuselage-level attitude that does not subject any occupant (pilot or passenger) to more than the following forces: vertical, 25 g; longitudinal and lateral, 25 g, for 0.20 second and 45 g for 0.10 second, as measured in the pelvic region of a suitable anthropomorphic dummy having a weight and mass distribution of that of the heaviest occupant expected. It is permissible to meet the above requirements through emergency power, undercarriage design, structural deformation, an adequate seat/support restraint system, or a combination of the above. These requirements are based on several factors: (1) it does not appear realistic, in view of the excellent reliability of turbine power plants, to require the additional power to maintain an airborne recovery in all cases; (2) failure of one engine of a two-engine aircraft should allow emergency landings within these limits with crew and passenger seats designed for the purpose; (3) loss of one engine in an aircraft with four or more power plants will, in all likelihood, be able to recover under most conditions but, if not, should be able to make a landing at near-design maximum sink rates.

c. Asymmetric Power - Asymmetric power shall apply to multiengine aircraft, except where otherwise stated, under the following conditions:
   1. Critical engine inoperative and in minimum drag condition.
   2. Remaining engines at maximum continuous power.

d. Directional Control - It shall be possible to execute heading changes in either direction without inducing dangerous characteristics. Heading changes of 15 degrees shall be demonstrated except that heading change at which the rudder pedal force is greater than 125 pounds need not be exceeded. The demonstration shall be under the following conditions:
   1. Power for level flight not greater than maximum continuous.
   2. Most unfavorable cg.
   3. Gear up.
   4. Flaps in approach position.

e. Lateral Control - It shall be possible to execute 20-degree banked turns with and against the inoperative engine. Demonstration shall be under the following conditions:
1. Most unfavorable cg.
2. Gear retracted and extended.
3. Wing flaps in the most favorable climb position.
4. Maximum to gross weight.

f. Minimum Control Speed - In the cruise or CTOL configurations, minimum control speed shall not be limited by unsatisfactory lateral-directional control with most critical asymmetric power conditions. Minimum control speed may be determined by conventional stall or by achievement of maximum trimmed lift as limited by longitudinal control power.

g. Touchdown Control - From hover to minimum forward speed, not determined by control power, it shall be possible to perform controlled level attitude touchdown following critical engine failure from any altitude. From altitudes and speeds outside the "deadman" zone, it shall be possible to execute controlled, level attitude landings within the structural limits of the aircraft.

2.8.4 Integrated Control System Failure

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

2.8.5 Pilot Induced Oscillations

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	There should be no tendency for a sustained or uncontrollable oscillation resulting from the effort of the pilot to maintain a steady flight path, or to maneuver the aircraft within its flight envelope. This should also apply following a failure in a power control or stability augmentation system.
USAAVLABS TR 65-45	No specifications

2.8.6 Autogyro Flight

MIL-H-8501A	No specifications
MIL-F-8785	No specifications
AGARD TR-408	No specifications
USAAVLABS TR 65-45	No specifications

DESIGN FACTORS TO BE CONSIDERED IN FORMULATION OF WINGED HELICOPTER DESIGN SPECIFICATIONS

In writing mission task performance oriented design specifications, it is necessary to consider design factors which can influence the aircraft's mission task performance capability. Some of these factors were qualitatively established for winged helicopters in interviews with personnel involved in the design and testing of winged helicopters. These data are based on subjective opinions of the personnel interviewed and thus should be verified through flight tests. However, they do provide a fair indication of some design factors which influence the aircraft's task performance capability, and thus should be considered in formulation of design specifications.

Listed under the applicable flight regimes are those design parameters which can adversely affect the aircraft mission task performance capability. The flight regimes considered are: hover, low-speed flight (3 to 120 knots); low-speed landing approach (80 to 3 knots); and high-speed flight (120 knots to V_{max}). Since none of the aircraft considered in this study had a distinct transition flight regime in going from the low-speed to the high-speed flight regime, it was not included in the flight regimes considered. Items to be considered which concern the whole flight envelope are listed under "Miscellaneous Problems."

The design factors established and some of their possible undesirable effects are as follows:

1. Hover

   a. Wing Effects

      (1) Increased vertical drag
      (2) Reduced roll responsiveness
      (3) Roll disturbances when rotor downwash ground turbulence strikes wing
      (4) Ground clearance problems in close-to-ground hover

   b. Pitch disturbances from the rotor downwash on the horizontal tail.

   c. Vertical Tail Effects

      (1) Increased damping and drag in hovering turns
      (2) Blanketing of tail rotor, thus reducing tail rotor efficiency

2. Low-Speed Flight (3 to 120 Knots)

a. Wing Effects

(1) Increased vertical drag at very low speeds
(2) Reduced roll responsiveness without ailerons
(3) Roll disturbances when rotor downwash ground turbulence strikes wing
(4) Reduced rate of climb
(5) Higher gust sensitivity
(6) Reduced rotor control power due to rotor unloading
(7) Autorotation difficulty without wing unloading
(8) Ground clearance problems in close-to-ground maneuvers

b. Pitch disturbances from rotor downwash on the horizontal tail

c. Vertical Tail Effects

(1) Limited lateral flight
(2) Blanketing of tail rotor, thus reducing tail rotor efficiency

d. Auxiliary Propulsion Effects

(1) Attitude control problems, depending upon auxiliary thrust unit location

3. Low-Speed Landing Approach (80 to 3 Knots)

a. All Low-Speed Flight Effects Apply

b. Wing Effects

(1) Autorotation entry can cause rotor speed control problems if wing is not unloaded
(2) Wing stall can cause roll and yaw oscillations in high rates of descent
(3) Wing turbulence can cause rotor instability during descents
(4) Wing can obscure ground visibility during steep flares

c. Horizontal tail can produce pitch damping during landing flare

d. Vertical tail can cause directional control problems in cross-wind landings

4. High-Speed Flight (120 Knots to V_{max})

a. Wing Effects

(1) Reduced roll responsiveness without ailerons
(2) Higher gust sensitivity
(3) Wing lift can cause dangerous rotor speed decay on autorotation entry

b. Auxiliary Propulsion Effects

(1) Rapid application of thrust can cause attitude control problems, depending upon auxiliary thrust unit location
(2) Sudden loss of auxiliary propulsion can cause rotor load problems

c. Rotor Effects

(1) Longitudinal control sensitivity can become excessive with speed
(2) Rotor vibrations can increase with speed on a loaded rotor
(3) Rotor speed is more difficult to control with increasing speed

5. Miscellaneous Problems

a. Selection of optimum trim condition at a given speed

b. Wing rotor lift sharing control, especially in high-speed maneuvers

c. Lack of control force gradient can make coordinated maneuvers difficult

d. Tail rotor clearance could create problems in close to ground flares

e. Pilot exit in an emergency

f. Unconventional piloting cues

PLAN FOR ADDITIONAL STUDIES

The general agreement of military personnel on the state-of-the-art advances in flying and handling qualities requirements specifications offered by the mission task performance oriented approach was evident in this study. However, it was found that insufficient data are available for a systematic evaluation of winged helicopter flying and handling qualities requirements. The available data are inadequate for an evaluation of the test-bed aircraft's conformance to current specifications, and data for an objective mission task performance capability evaluation are nonexistent. Thus, the additional studies should provide data for both of the above areas.

An excellent source for generating flying and handling qualities requirements information would be a variable stability aircraft. In this aircraft, provisions for varying the control powers and airframe dynamic characteristics would be incorporated which, together with performance measuring and processing equipment, would provide a tool for determining the relationship between aircraft mission task performance capability and its control and dynamic characteristics.

If a variable stability aircraft is not available, tests should be performed on a number of aircraft which are sufficiently different in design, dynamic response, and control response characteristics to permit an evaluation of the effect of various design parameters on the aircraft's mission task performance capability.

The flight tests required are divided into two parts:

1. Specification Conformance Evaluation Flight Tests
2. Mission Task Performance Capability Evaluation Flight Tests

The variable stability aircraft should be operated at a sufficient range of control powers and dynamic stability characteristics to permit the determination of a control power/aircraft stability envelope for adequate mission task performance capability.

Where a variable stability aircraft is not available, tests must be conducted for a forward, aft, and normal C.G. location.

The following measurements must be taken in order to obtain the necessary data:

ON-BOARD MEASUREMENTS

1. Control Positions:

   Longitudinal Cyclic Pitch Control
   Lateral Cyclic Pitch Control
   Collective Pitch Control
   Rudder Control
   Engine Throttle
   Auxiliary Propulsion Throttle

2. Displacement Measurements:

   Pitch, Roll, and Yaw Attitudes
   Pitch, Roll, and Yaw Angular Velocity
   Pitch, Roll, and Yaw Angular Accelerations
   Airspeed
   Horizontal Acceleration
   Altitude
   Vertical Acceleration at C.G.
   Heading Rate
   Rotor RPM
   Normal, Longitudinal, and Lateral Load Factor at the Pilot Station
   Normal, Longitudinal, and Lateral Vibration at the Pilot Station
   Normal, Longitudinal, and Lateral Vibration of the Controls
   Normal, Longitudinal, and Lateral Load Factor at the C.G.

EXTERNAL MEASUREMENTS

Longitudinal Position
Lateral Position
Vertical Position
} Positions relative to a fixed reference

Wind Velocity
Wind Direction
Wind Gust, Spread, and Magnitude
Ambient Temperature
Visibility
Ceiling

All of these measurements are not necessary for each task to be performed, but since all of them must be available, their recording will provide additional useful information.

SPECIFICATION CONFORMANCE EVALUATION FLIGHT TESTS

Static Trim

Trim points are to be taken at 20-kn intervals starting with a rearward velocity of at least 30 kn and up to maximum forward velocity. Trim points at hover and maximum velocity must be taken in addition to the points taken at 20-kn intervals.

Sideward Flight

Trim points are to be taken at 10-kn lateral speed intervals from hover to 40 kn, or maximum lateral velocity, whichever is less. Runs are to be made both to the right and to the left.

Control Power

Data should be taken with Stability Augmentation Systems (SAS), Automatic Stability Equipment (ASE), etc. on, a single system failure, and SAS or ASE off.

1. Pitch Control Power

   a. In steady hover, make a 1-inch step pitch control input and hold for 1 second. Make both "pull and hold" and "push and hold" inputs.
   b. In steady hover, make a step total (or as large as possible) pitch control input and hold for 1 second. Make both "pull and hold" and "push and hold" inputs.
   c. In high-speed flight, demonstrate maximum permissible load factor or wing stall, whichever comes first, using only longitudinal control.

2. Roll Control Power

   a. In steady hover, make a 1-inch step lateral control input and hold for 1/2 second. Make both right and left control inputs.
   b. In steady hover, make a step total (or as large as possible) lateral control input and hold for 1/2 second. Make both right and left control inputs.
   c. In high-speed flight, demonstrate the aircraft's maximum roll capability.

3. Yaw Control Power

a. In steady hover, make a 1-inch step directional control input and hold for 1 second. Make both right and left control inputs.
b. In steady hover, make a step total (or as large as possible) directional control input and hold for 1 second. Make both right and left control inputs.

Dynamic Stability

Time histories of dynamic response to control inputs specified below are required. The time histories should be generated at 30-kn speed increments in the speed range from 30 kn backward flight up to and including maximum forward speed.

Control Inputs:

a. A step longitudinal control input
b. A pulse longitudinal control input
c. A step lateral control input
d. A pulse lateral control input
e. A step directional control input
f. A pulse directional control input

The magnitudes of control inputs shall be sufficient to cover up to 80 percent of the design flight envelope limits (the minimum shall be that required to produce 5.0 degrees per second pitching velocity or a load factor increment of 1.0 g, whichever occurs last).

Specification Conformance Data Evaluation

The aircraft's specification conformance is then evaluated by filling out the Specification Conformance Evaluation Form.

MISSION TASK PERFORMANCE CAPABILITY EVALUATION FLIGHT TESTS

The mission task performance study is divided into four flight regimes:

Hover and Vertical Flight
Low-Speed Flight
Transition
High-Speed Flight

Tasks are listed for each flight regime.

Hover and Vertical Flight

a. Precision Hover (IGE, OGE) -
Position the aircraft in hover at a prescribed altitude with the aircraft's C.G. over a designated point on the ground. For 1 minute, maintain constant heading, position, and altitude.

b. 360 Degree Hovering Turns (IGE, OGE) -
Position the aircraft in hover at a prescribed altitude with the aircraft's C.G. over a designated point on the ground. Execute a 360-degree turn, maintaining constant altitude and keeping the aircraft's C.G. over the designated point on the ground. Both right-hand and left-hand turns are to be performed.

c. Vertical Climb -
Position the aircraft in hover at a prescribed altitude with the aircraft's C.G. over a designated point on the ground. Execute a vertical ascent to a prescribed higher altitude, keeping the aircraft's C.G. over the prescribed point and maintaining the prescribed heading and rate of climb. Stop aircraft in a steady hover at the prescribed altitude.

d. Vertical Descent -
Position the aircraft in hover at prescribed altitude with the aircraft's C.G. over a designated point on the ground. Execute a vertical descent to a prescribed lower altitude,keeping the aircraft's C.G. over the designated point and maintaining constant heading and rate of descent. Stop aircraft in a steady hover at the prescribed lower altitude.

Low-Speed Flight (to be performed with auxiliary propulsion off)

a. Acceleration and Deceleration -
Set up a steady-state hover at a prescribed altitude. Accelerate at maximum rate of acceleration to a prescribed speed, maintaining constant altitude and heading. From steady, level flight at a prescribed airspeed and altitude, decelerate at maximum rate of deceleration to a hover, maintaining constant heading and altitude.

b. Sideward Flight (IGE, OGE) -
Set up a steady hover at a prescribed altitude with the aircraft's C.G. over the end point of a straight line and with the fuselage at right angles to the line. Fly sideways at a designated lateral velocity, keeping the C. G. of the aircraft along the line and maintaining constant heading and altitude. Bring the aircraft to a hover at the opposite end of the line, and repeat the task in the

opposite direction.

c. Air-Taxi Over Prescribed Course -
1) Position the aircraft in hover over the beginning point of the prescribed course and headed along the first leg of the course. Air-taxi aircraft over the course, keeping the aircraft's centerline along the course and maintaining constant altitude and a prescribed velocity. Stop at corners to turn to the next leg of the course.
2) Position the aircraft in hover with the C.G. over the beginning point of the prescribed course and headed in a designated direction. Air-taxi aircraft over the prescribed course, keeping the aircraft's C.G. over the course and maintaining constant heading and altitude. Stop at corners to change direction of motion, and maintain a prescribed velocity and yaw angle along the legs of the course.

d. Pullouts -
From steady, level flight at a designated velocity and altitude, execute a symmetrical pullout attaining a prescribed value of normal load factor and rate of climb. Maintain the prescribed rate of climb for a predetermined length of time.

e. Pushovers -
From steady, level flight at a designated velocity and altitude, execute a symmetrical pushover attaining a prescribed value of normal load factor and rate of descent. Maintain the prescribed rate of descent for a designated length of time.

f. Coordinated Figure-8 Turns -
From steady, level flight at a designated velocity and altitude, execute a figure-8 turn attaining a prescribed bank angle within a designated time limit and maintaining constant velocity and altitude.

g. Quick Turnaround -
From steady, level flight at a prescribed altitude and velocity, reverse the direction of travel and accelerate to the prescribed velocity maintaining constant altitude.

h. Turn Over Target and Gunnery Run -
At a prescribed altitude and velocity, approach a designated target. When the aircraft is over the target, execute a turn and perform a gunnery run on the target within a specified time interval. Both turns to the right and to the left should be tried.

i. Autorotation Entry and Steady-State Autorotative Descent and Landing -
In steady, level flight at prescribed velocity and altitude, execute a rotor power chop. Establish a designated rate of descent, velocity, and rotor RPM. Land aircraft in a predetermined area, making the touch down at a prescribed sink rate.

j. Approach and Landing -
Approach a designated landing area at a prescribed velocity and altitude. At a predetermined distance from the landing area, establish a prescribed descent rate and velocity. Land the aircraft within a designated part of the landing area. For an assault transport or armed escort-type aircraft, two ways of approach to the landing area must be executed: a treetop level approach and an approach from an altitude which provides security from small-arms fire.

k. Terrain Following -
Fly over a specified strip of terrain following a specified course and maintaining a prescribed velocity and terrain clearance.

Transition

a. Straight and Level Transition -
In straight, level flight at a prescribed velocity, with auxiliary propulsion initially off, gradually lower the collective pitch either to the high-speed flight setting or until the wing begins to stall. Use auxiliary propulsion to maintain straight, level flight and constant velocity. These runs should be repeated at 10-kn intervals to cover the speed regime from 80 to 140 kn.

b. Acceleration and Deceleration -
From straight, level flight at a prescribed low velocity and altitude, with auxiliary propulsion initially off, accelerate to a designated high velocity at maximum rate of acceleration, while gradually reducing collective pitch to the high-speed flight setting. Use auxiliary propulsion for acceleration. Maintain constant heading and altitude. Establish steady, level flight at the designated high speed, and maintain this speed and altitude for a prescribed time interval. From these conditions, decelerate at maximum rate of deceleration and establish the originally prescribed low-speed flight condition, with auxiliary propulsion off, maintaining constant altitude and heading.

c. Transition Climb -

(1) With auxiliary propulsion initially turned off, establish straight, level flight at an assigned altitude and velocity. Execute a symmetrical pull-up and establish a command rate of climb and velocity. Bring the collective pitch to the high-speed flight setting within a prescribed time from the initiation of the maneuver, maintaining the command rate of climb and velocity by using auxiliary propulsion.

(2) With collective pitch at the high-speed flight setting and auxiliary propulsion turned on, establish straight, level flight at an assigned altitude and velocity. Execute a symmetrical pull-up and establish a command rate of climb and velocity by use of collective pitch.

d. Transition Descent -

With collective pitch at the high-speed flight setting and auxiliary propulsion turned on, establish straight, level flight at an assigned altitude and velocity. Execute a pushover and establish a prescribed velocity and rate of descent. Within a prescribed time limit, throttle down and turn off the auxiliary propulsion, maintaining command rate of descent and velocity by use of collective pitch.

e. Transition Figure-8 Turns -

With auxiliary propulsion turned off, establish steady, level flight at a prescribed altitude and velocity. Execute a Figure-8 turn coordinated within a prescribed time limit, and attain a command value of bank angle on each circular segment. At the start of the turn, begin to lower collective pitch, reaching the high-speed flight setting in the first half of the maneuver. Maintain constant velocity and altitude by using auxiliary propulsion. In the second half of the maneuver, gradually reduce auxiliary propulsion to zero, and maintain constant altitude and velocity by increasing collective pitch.
This maneuver shall be performed in two directions; i.e., starting with a turn to the right and then repeating it with an initial turn to the left.

<u>High-Speed Flight (to be performed with auxiliary propulsion on and collective pitch at the high-speed flight setting)</u>

a. Acceleration; Steady, Level Flight; and Deceleration -

From steady, level flight at a prescribed altitude and velocity, accelerate within a designated time interval to a prescribed higher velocity, maintaining constant altitude and heading. Maintain straight and level flight at the higher velocity for a specified length of time. At the end of this time, decelerate the aircraft, within a designated time interval, to the prescribed lower velocity.

b. Pull-up and Pushover -
From steady, level flight at an assigned altitude and velocity, execute a symmetrical pull-up. Establish a prescribed velocity and rate of climb. At the prescribed higher altitude, execute a pushover, develop a specified normal load factor, and establish steady, level flight at the original velocity. Maintain a constant heading throughout the maneuver.

c. Pushover and Pull-up -
From steady, level flight at an assigned higher altitude and velocity, execute a symmetrical pushover, attain an assigned value of load factor, and establish a prescribed velocity and rate of descent, maintaining a constant heading. At the specified lower altitude, execute a symmetrical pullout and establish steady, level flight at the original velocity.

d. Coordinated Figure-8 Turns -
From steady, level flight at a prescribed altitude and velocity, execute a coordinated Figure-8 turn within a prescribed time limit, attaining a specified value of bank angle in each half of the maneuver. Maintain constant altitude and velocity throughout the turn.

e. Turn Over Target and Gunnery Run -
At a prescribed altitude and velocity, approach a designated target. When the aircraft is over the target, execute a turn and perform a gunnery run on the target within a specified time interval. Both right and left turns should be tried.

f. Terrain Following -
Fly over a specified terrain, following a specified course and maintaining a prescribed velocity and terrain clearance.

The mission tasks described above must be performed by at least three pilots, each pilot performing each task five times. This procedure is necessary in order to obtain statistically significant data for evaluation of the aircraft's mission task performance capability.

Task Performance Data Evaluation

The measurements taken during the task performance flight tests listed above are to be used for an objective evaluation of the aircraft's mission task performance capability. The applicable portions of the mission task performance evaluation questionnaire must be filled in. The task performance of the subject aircraft must be compared to the established task performance tolerances for the class of winged helicopters in which the subject aircraft is assigned. The comparison of actual task performance with the prescribed tolerances can be based on mean errors, standard deviations, or other equivalent error values calculated from the flight test results. The form of data must permit rapid comparison of actual task performance with established task performance tolerances.

OBJECTIVE TASK PERFORMANCE EVALUATION STUDY

Winged helicopter handling qualities studies conducted by Sikorsky have emphasized the need for objective precision task performance data on which to base future specifications. Although visits to the manufacturers of existing winged helicopters indicated that no such data existed for these aircraft, it was believed that an investigation of flight test programs during which objective measurements were taken would allow the formulation of more realistic plans for future work in this area. A review of the literature has shown that very little data exist relating to the specific problems of precision task performance measurement in helicopters and VTOL flight tests. One exception is the hovering trials, conducted under ANIP funding, to measure precision hovering performance with the contact analog display. The technique employed a number of observers placed around the flight field to record errors in longitudinal position, lateral position, and height. Each observer was equipped with a sighting device through which he observed and recorded deviations every few seconds. This technique was effective for display evaluation, but the sampling rate was not high enough to reproduce the vehicle motions, which are of interest in a handling qualities evaluation. The other two areas where some objective performance data exist are air-to-ground gunnery and instrument approach tasks. The gunnery tasks have been evaluated through analysis of motion picture data taken by a bore sighted camera. The resulting data were presented in terms of average azimuth and elevation errors. Instrument approach data have been collected in a number of instrumentation evaluations and handling qualities studies which will be discussed later.

After sources of data were discussed with both USAAVLABS and HEL personnel, several government agencies were visited to determine whether any new work relevant to objective task performance measurement had been carried out. The visits revealed that very little flight test research involving objective performance measurement had been carried out. The exceptions were work done on instrument landing approaches and timed travel through various closed courses. The measurement of ILS performance contributed very little in terms of measurement techniques because of the simplicity in recording raw glide slope and localizer error. Studies involving timed travel left some doubt as to how the researchers insured that the aircraft followed the prescribed course.

Pilot opinion data were used with differing degrees of confidence by the agencies contacted. Some agencies are willing to place almost total reliance on such data, while others use them mainly as a backup to the other measures taken. Initial investigations of more advanced techniques, such as power spectral analysis of control data, secondary task measures, and physiological measurements are being carried out. However, more tests of their contribution to actual task performance measurements must be carried out before these advanced techniques can be used as part of general task performance evaluation techniques.

RESULTS

The results of this winged helicopter flying and handling qualities study are as follows:

1. Major Army missions for winged helicopters, the related critical mission tasks, and approximate values of mission task performance tolerances were determined.

2. A format for mission task performance oriented winged helicopter design specifications was prepared.

3. Items applicable to winged helicopters from current specifications were collected under appropriate items of the new specifications format.

4. Potential problem areas in winged helicopter design were identified and listed.

5. Questionnaires for evaluation of aircraft characteristics and aircraft task performance capability were developed.

6. A plan for additional studies needed to generate the data necessary for development of mission task performance oriented winged helicopter design specifications was formulated.

CONCLUSIONS

Consideration of the results of this study led to the following conclusions:

1. The mission task performance oriented approach to flying and handling qualities specifications will help to assure an aircraft's capability to efficiently perform its design mission to an extent not possible with currently used specifications.

2. Task performance data for current winged helicopter test beds which can be used to establish mission task performance oriented flying and handling qualities requirements is non-existent.

RECOMMENDATIONS

Based upon the results and conclusions of this study the following recommendations are made:

1. The Army task performance requirements must be reviewed and substantiated by objective measurements taken during actual task performance.

2. Task performance evaluation techniques must be developed for critical Army missions.

3. Flight test programs must be implemented to establish the extent to which the helicopter design parameters influence the aircraft's mission task performance capability.

REFERENCES CITED

1. FLYING AND HANDLING QUALITIES REQUIREMENTS OF WINGED HELICOPTERS, Contract DA 44-177-382(T).

2. GENERAL REQUIREMENTS FOR HELICOPTER FLYING AND GROUND HANDLING QUALITIES, MIL-H-8501A.

3. MILITARY SPECIFICATION, FLYING QUALITIES OF PILOTED AIRPLANES, MIL-F-8785.

4. RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES, AGARD TR-408.

5. Curry, Paul R. Maj., and Matthews, James T. Jr., SUGGESTED REQUIREMENTS FOR V/STOL FLYING QUALITIES; USAAVLABS Technical Report 65-45, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, June 1965.

6. SUMMARY REPORT HIGH-PERFORMANCE-HELICOPTER PROGRAM PHASE I, TRECOM TR 63-42.

7. HIGH-PERFORMANCE HELICOPTER PROGRAM. SUMMARY REPORT PHASE II, TRECOM Technical Report 64-61, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, October 1964.

8. HIGH-PERFORMANCE UH-1 COMPOUND HELICOPTER MANEUVER FLIGHT TEST PROGRAM, USAAVLABS Technical Report 66-17, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, February 1966.

9. Blackburn, W.E., and Whitfield, A. A., UH-2 HELICOPTER HIGH-SPEED FLIGHT RESEARCH PROGRAM UTILIZING JET THRUST AUGMENTATION, Final Report USAAVLABS TR 65-14, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, March 1965.

10. Blackburn, W.E., and Whitfield, A.A., UH-2 JET-AUGMENTED HIGH-SPEED RESEARCH HELICOPTER MANEUVERABILITY AND DYNAMIC STABILITY EVALUATION; USAAVLABS Technical Report 65-23, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, July 1965.

11. FLIGHT RESEARCH PROGRAM TO EVALUATE METHODS OF IMPROVING COMPOUND HELICOPTER MANEUVER CAPABILITY, Final Report. Not published yet.

12. Foulke, William K., EXPLORATION OF HIGH SPEED FLIGHT WITH THE XH-51-A RIGID ROTOR HELICOPTER, USAAML Technical Report 65-25, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, June 1965.

13. Wyrick, Donald R., EXTENSION OF THE HIGH-SPEED FLIGHT ENVELOPE OF THE XH-51-A COMPOUND HELICOPTER; USAAVLABS Technical Report 65-71, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, December 1965.

14. Garren, J.F., Jr., Kelly, J.R., and Reeder, J. P., A VISUAL FLIGHT INVESTIGATION OF HOVERING AND LOW SPEED VTOL CONTROL REQUIREMENTS, NASA TN-D-2788, April 1965.

15. Garren, J. R., Jr., Kelly, J. R., and Reeder, J. P., EFFECTS OF GROSS CHANGES IN STATIC DIRECTIONAL STABILITY ON V/STOL HANDLING CHARACTERISTICS BASED ON A FLIGHT INVESTIGATION, NASA TN-D-2477, October 1964.

16. USAF PILOT FACTOR PROGRAM (Prepared by the Instrument Evaluation Branch of the USAF Instrument Pilot Instructor School and the Bunker-Ramo Human Engineering Support Group).

17. Vreuls, D., and Rheinlander, T. W., ALLOCATION OF CONTROL TASKS, 1-A; INFLIGHT DETERMINATION OF PILOT PERFORMANCE FOR SPECIFIC FORCE WHEEL CONTROL DYNAMICS IN THE T-29 AIRCRAFT, Bunker-Ramo Corporation Engineering Report SA-65-1.

18. Vreuls, D., and Rheinlander, T. W., ALLOCATION OF CONTROL TASKS, 1-B; INFLIGHT DETERMINATION OF PILOT PERFORMANCE WITH SPECIFIC FORCE WHEEL CONTROL DYNAMICS IN THE T-29 AIRCRAFT, Bunker-Ramo Corporation Engineering Report SA-65-2.

19. Sardanowsky, W., and Harper, H.P., SPECIFICATION CONFORMANCE EVALUATION FORM, Sikorsky Aircraft SE-7663, November 11, 1966, Enclosure (2).